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Technical Report

No. 13379

Automated Mechanical Transmission Test Summary and Component Analysis

Contract Number DAAE07-86-C-R028

April 1988

R. C. Holmes
Eaton Corporation
Corporate Research & Development
Detroit Center
26201 Northwestern Highway
P. O. Box 766
Southfield, MI 48037
Eaton Technical Report No. 88018

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U.S. ARMY TANK-AUTOMOTIVE COMMAND
RESEARCH, DEVELOPMENT & ENGINEERING CENTER
Warren, Michigan 48397-5000

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Test Summary and Component Analysis**

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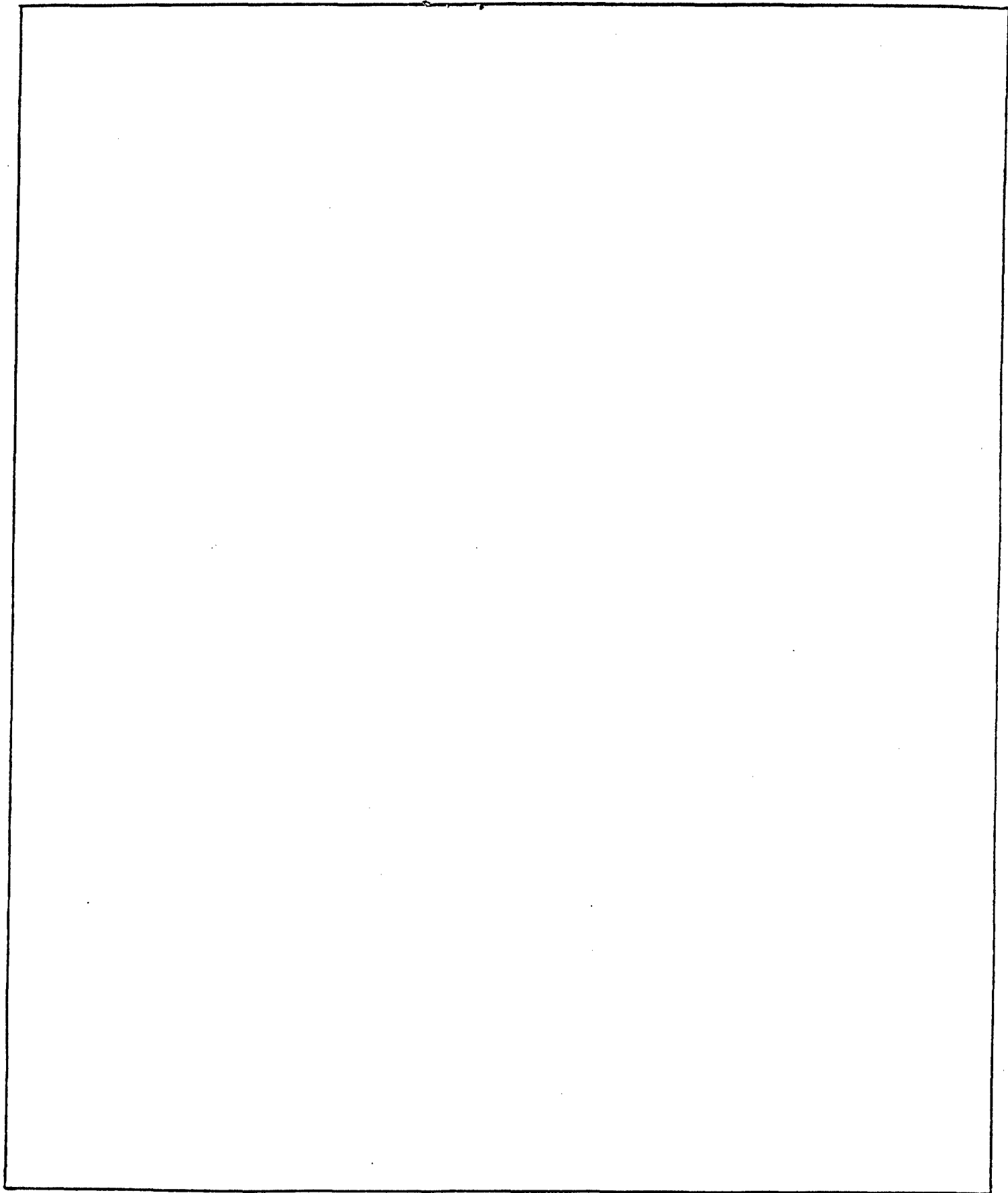
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) Eaton Corporation has contracted with the United States Army to design, develop and deliver a prototype automated mechanical transmission system for the M939-series 5-ton truck to demonstrate technical feasibility. The system design used the Eaton TSO-11616 transmission in combination with the Cummins NHC-250 engine and Spicer AS1402SD heavy-duty clutch. Test plans were conducted at Eaton and Aberdeen Proving Grounds to evaluate both performance and durability. This report covers the test results, teardown inspection and transmission rebuild for the Modern Technology demonstration truck.					
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SUMMARY

Automated mechanical transmissions have been developed by adding electronic controls, actuators and sensors to manual operated master clutch and multispeed transmission assemblies to achieve fully automatic operation.

An automated mechanical transmission with an integral transfer case was designed, developed and delivered to the U. S. Army Tank-Automotive Command (TACOM) in an M939- series 5-Ton Tactical Truck. This system was subjected to a Technical Feasibility Test at Aberdeen Proving Grounds, which included a 10,000-mile endurance test over the Munson, Perryman and Churchville test courses.

The transmission system successfully passed the test plan, which would indicate that the performance and reliability of the M939-series 5-ton performance would not be jeopardized by this alternative automatic transmission concept.

This report specifically addresses the teardown inspection upon completion of the Aberdeen Technical Feasibility Test and the rebuild of the transmission system for the "Modern Technology Demonstration" 5-ton truck being assembled for the TACOM by General Motors - Military Vehicles Operation.

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1.0. INTRODUCTION

This final technical report, prepared by the Corporate Research & Development-Detroit Center of Eaton Corporation for the U. S. Army Tank-Automotive Command (TACOM) under Contract DAAE07-86-C-R028, describes the teardown inspection and analysis of the TS0-11616 automated mechanical transmission with integral transfer case upon completion of a successful Technical Feasibility Test performed at the U. S. Army Aberdeen Proving Ground, Aberdeen, Maryland. In addition, a summary of the Eaton-performed test plan, as well as the Aberdeen Proving Ground test plan, is included. The TS0-11616 automated mechanical transmission was rebuilt with significant improvements for the TACOM'S Modern Technology Demonstrator 5-ton truck. The changes in construction and performance are also described.

Eaton Corporation is a major worldwide supplier of heavy-duty, constant-mesh, manually operated truck transmissions. Eaton Corporate Research & Development-Detroit Center has been applying electronics to transmission controls since the early 1970's. In the mid-1970's, automation of mechanical transmissions and clutches was demonstrated, and a significant program to apply transmission automation techniques to commercial transmissions was initiated in 1980.

Along with the dry clutch approach, Eaton also pursued the more traditional route and developed an automated mechanical transmission that utilizes a torque converter. Information on this unit is found in Appendix A.

The remainder of this report will concern itself with the dry clutch transmission.

This technology was demonstrated to TACOM personnel and, consequently, the following series of contracts were issued to Eaton Corporation for evaluation, design, development, test, field service and teardown analysis and rebuild of a transmission system.

- DAAE07 - 81-C-4054, Evaluation Study and Preliminary Test
- DAAE07 - 82-C-4121, Design and Development
- DAAE07 - 85-R-R194, Field Service Support
- DAAE07 - 86-C-R028, Teardown Analysis and Rebuild

As a result of the U. S. Army initiative, a 16-speed automated mechanical transmission using a standard Spicer AS1402SD clutch along with an integral transfer case was designed, developed and tested. The performance requirements of the standard M939-series 5-ton tactical truck were used as the performance and durability specification.

Test plans at Eaton Proving Grounds and Aberdeen Proving Grounds have shown that the M939 performance specifications can be achieved without sacrifice or limitations in operation. Both at the system level and the component level there are no capability or durability limitations demonstrated that should preclude the pursuit of this alternative automatic transmission technology for U. S. Army tactical trucks.

2.0. STATEMENT OF OBJECTIVES

The primary goal was to evaluate Eaton Corporation's Automated Mechanical Transmission technology in a U. S. Army M939-series 5-ton tactical truck. A 16-speed automatic transmission was designed, developed, tested, inspected and rebuilt for this purpose.

3.0. CONCLUSIONS

3.1. Teardown Inspection

3.1.1. Master Clutch Assembly. Visual inspection of the clutch indicates that there was no thermal or mechanical damage. Measurement of the wear surfaces of the clutch assembly indicates that only 10% of the total allowable axial wear of the eight-friction surfaces occurred.

3.1.2. Mechanical Transmission. The gearing was found to be in excellent condition. One gear showing distress had insufficient case depth.

The ball and roller bearing supporting the countershafts, input shafts and output shaft were in excellent condition. An axial needle thrust bearing failed after a new mainshaft had been installed without adequate adjustment.

The dog clutch wear appeared typical for a transmission with this level of accumulated shifts.

During operation at the Churchville "B" course on the 29% grade, with a 15000 pound gun carriage, the transmission exhibited kickout in 3rd gear causing severe torsional impact loads. This eventually led to a mainshaft failure after hundreds of impacts. The mainshaft was replaced. A step lock spline was incorporated at reassembly and this greatly reduced kick out. Eaton also recommended that a special driving procedure be used on the grade. A formal analysis of the failure is contained in Eaton's Technical Report 86011 (See selected Bibliography).

3.1.3. Shift Actuators. There are two electropneumatic shift actuators: one for the main box and one for the four-speed auxiliary section. No distress was found in any elements. Shift fork pad wear was within allowable limits.

3.2. Rebuild for Modern Technology Demonstration Truck

The mechanical transmission was rebuilt with new gaskets, bearing seals and dog clutches. These are typical parts supplied in an Eaton transmission rebuild.

Rebuild modifications to the transmission assembly were:

- New main case to allow internal upshift brake for ease of power pack removal
- New transfer case gearing to improve noise level
- Tapered tooth dog clutch in direct auxiliary position to eliminate kick-out under high torque
- High thrust load capability roller bearing for absorption of front driveshaft axial loads

The complete electronics control package and wiring harness was replaced to upgrade to Eaton's latest level of control and packaging technology. Features are

- Complete microprocessor control system with two 16-bit Intel microprocessors
- Fault tolerant control algorithms employed
- Predictive algorithms improve acceleration times
- Electronic engine communication link provided
- Reduced parts count for higher reliability
- Packaging proven to be more tolerant to temperature extremes, vibration, water immersion and EMI/RFI
- All connectors upgraded to military standards
- This electronic upgrade provided at no additional cost to the U. S. Army.

3.3. Summary of Test Results

The Eaton TSO-11616 Automated Mechanical Transmission with integral transfer case met or exceeded all of the requirements of Eaton and Aberdeen Proving Grounds test plans. No performance limitations of the M939-series 5-ton truck requirements were imposed by this transmission concept.

4.0. DISCUSSION

4.1. Description of Transmission System

The base transmission selected for this application is Eaton Model TSO-11616. This is one of a new family of transmissions under development which are called "Twin Splitter" transmissions. The model designation, TSO-11616, has the following interpretation:

- TS - Twin Splitter Family of Twin Countershaft Transmissions
- O - Overdrive Transmission Ratios
- 11 - 1,150 lb-ft Input Torque Rating
- 6 - Multimesh Gearing Employed
- 16 Speeds Forward

The Twin Splitter transmission is an extension of the TS-1312A "Snapper" transmission technology with blocker mechanisms employed only in the auxiliary section. It is combined with a main section which uses the traditional constant mesh construction of Eaton Fuller transmissions.

The TSO-11616 transmission consists of a four-speed main box which is combined with a four-speed auxiliary section and an integral transfer case to obtain sixteen forward speeds.

The upshifting power path is to start in a designated front box gear ratio and split the front box ratio by means of shifting through each of the four auxiliary section's gear ratios until the auxiliary is in the overdrive gear. Then a compound shift occurs and the main box is shifted to the next highest gear and the auxiliary section is shifted back to the low gear position.

The gear ratios in the main section are as follows:

- Headset Ratio: $= 78/40 = 1.950 : 1$
- 4th Gear = Direct Drive $= 1 : 1$
- 3rd Gear $= 1.95 \times 48/45 = 2.080 : 1$
- 2nd Gear $= 1.95 \times 46/21 = 4.271 : 1$
- 1st Gear $= 1.95 \times 50/11 = 8.864 : 1$
- Reverse Gear $= 1.95 \times 46/11 = 8.154 : 1$

The auxiliary section and drop box ratios to the output shafts would be as follows:

- Drop Box Ratio $= 70/48 \times 42/70 = 0.875 : 1$
- Auxiliary Reduction Set $= 48/41 = 1.171 : 1$
- Output Ratio $= .875 \times 1.171 = 1.0244 : 1$
- Low Aux. $= 1.0244 \times 49/40 = 1.255 : 1$
- Int. Aux. $= 1.0244 \times 47/46 = 1.047 : 1$
- Dir. Aux. $= 1.00 \times .875 = 0.875 : 1$
- O.D. Aux. $= 1.0244 \times 41/58 = 0.724 : 1$

The ratio for each gear that is the product of the main box ratio and the auxiliary section ratio is found in Table 4-1.

This program was initiated at the Engineering & Research Center in 1979. In 1982, the Manufacturing Engineering Group at Eaton Transmission Division in Galesburg, Michigan, provided the hardware to build 34 prototypes of 3 models of the Twin Splitter family.

Eaton's Truck Components-Europe Engineering Group in Manchester, England, has released the Twin Splitter for production and supplies to several European truck builders.

The sixteen ratios of the TSO-11616 are obtained by combining the four-speed plus reverse main section with a four-speed auxiliary section, thereby yielding the sixteen speeds.

4.1.1. Automated System. In order to automate a mechanical transmission which is normally operated directly by the driver, the engine, clutch, transmission and electronic logic become a system which controls vehicle starts and transmission shifting.

Activating mechanisms must be added to replace the driver's hand and foot operations and a controller or electronic logic must replace the driver's decision-making process. Such a system is illustrated by the schematic diagram shown in Figure 4-1.

To provide the all-wheel drive function of the transfer case, an integral drop box is added to the base TSO-11616 transmission.

Table 4-1. Transmission Ratios

Gear	Ratio	%Step
Rev Low	$8.154 \times 1.255 = 10.23$	
Rev Dir	$8.154 \times .875 = 7.13$	
1 - 1st Low	$8.86 \times 1.255 = 11.12$	19.9%
2 - 1st Int	$8.86 \times 1.047 = 9.28$	19.6%
3 - 1st Dir	$8.864 \times .875 = 7.76$	20.8%
4 - 1st O.D.	$8.864 \times .724 = 6.42$	19.7%
5 - 2nd Low	$4.271 \times 1.255 = 5.36$	19.9%
6 - 2nd Int	$4.271 \times 1.047 = 4.47$	19.6%
7 - 2nd Dir	$4.271 \times .875 = 3.74$	20.8%
8 - 2nd O.D.	$4.271 \times .724 = 3.09$	18.5%
9 - 3rd Low	$2.08 \times 1.255 = 2.61$	19.9%
10 - 3rd Int	$2.08 \times 1.047 = 2.18$	19.6%
11 - 3rd Dir	$2.08 \times .875 = 1.82$	20.8%
12 - 3rd O.D.	$2.08 \times .724 = 1.51$	20.0%
13 - 4th Low	$1 \times 1.255 = 1.26$	19.9%
14 - 4th Int	$1 \times 1.047 = 1.05$	19.6%
15 - 4th Dir	$1 \times .875 = .875$	20.8%
16 - 4th O.D.	$1 \times .724 = .724$	
Overall Reduction Ratio = $11.12/.724 = 15.36$		

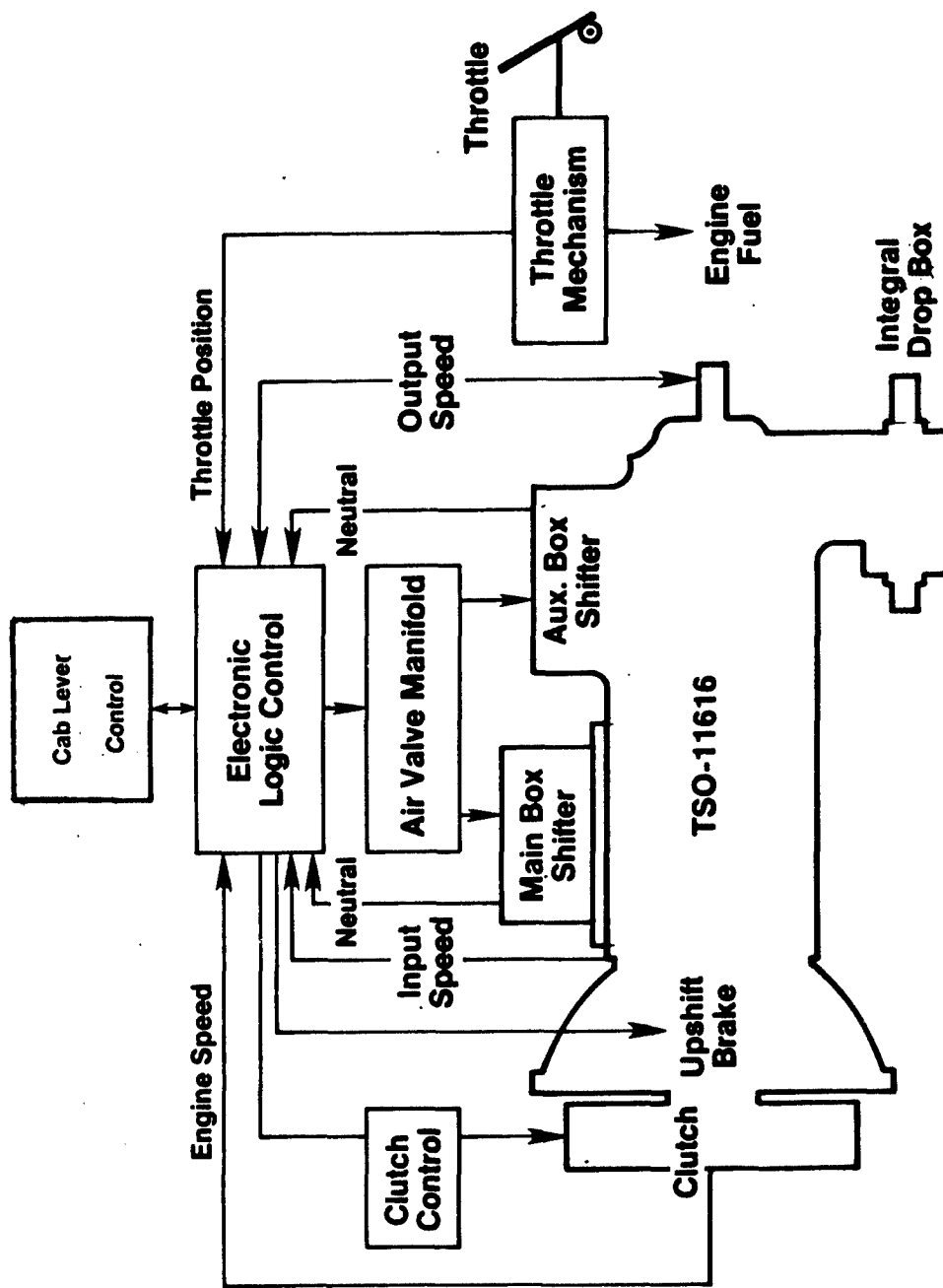


Figure 4-1 System Block Diagram

The additional components required to complete the system are as follows:

- Cab lever control for driver input.
- Clutch control mechanism for engaging and releasing the master clutch.
- Input brake for shift synchronization.
- Throttle mechanism or fuel control for manipulation of the engine, independent of the driver.
- Main box and auxiliary box shifter mechanisms to engage the desired gear.
- Air valve manifold with solenoid operators to actuate the brake, clutch and shifters.
- Electronic logic control to operate the complete system.

In some applications it is desirable to add the control and operation of transmission-driven PTO's, engine compression brakes, retarders, all-wheel drive or other driveline elements to the control system's functions.

4.2. Prediction of Performance

The performance of an M939 5-ton truck can be analyzed with a computer program, "Truck Driveline Analysis" and compared to the specified performance goals.

The analysis was done on the basis of having a minimum specification NHC-250 engine. A typical engine map is shown in Figure 4-2. The normal engine power curve data was input to the program and reduced by an engine efficiency of 84%. This gives an output torque of 550 lb-ft at 1500 RPM and 201 hp at 2100 RPM. This compares with the minimum specification engine.

The available power at the wheels was then reduced by an overall drivetrain efficiency of 90%. This available wheel horsepower can then be compared graphically to the resistance horsepower due to rolling resistance, air resistance and grade resistance.

The computer program inputs for this analysis can be listed as follows:

- **Engine: Cummins NHC-250**
 - 240 hp at 2100 RPM
 - 0 hp at 2400 RPM
 - 658 lb-ft at 1500 RPM
 - 547 lb-ft at 600 RPM
- **Transmission: Eaton TSO-11616 Ratios (TR)**

1	12.71	9	2.98
2	10.60	10	2.49
3	8.86	11	2.08
4	7.34	12	1.72
5	6.13	13	1.43
6	5.11	14	1.20
7	4.27	15	1.00
8	3.54	16	0.83

Integral Transfer Case Ratio: 0.875:1

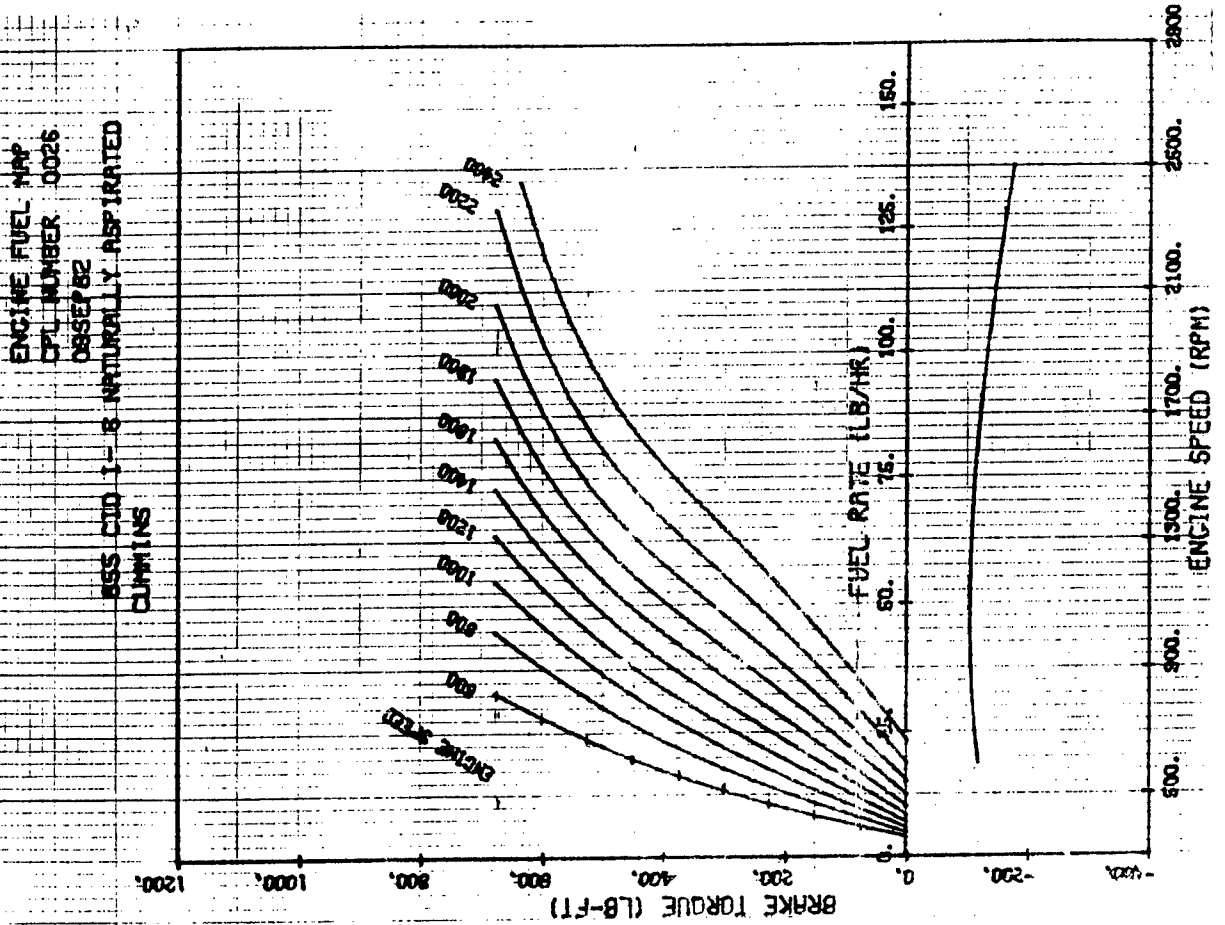
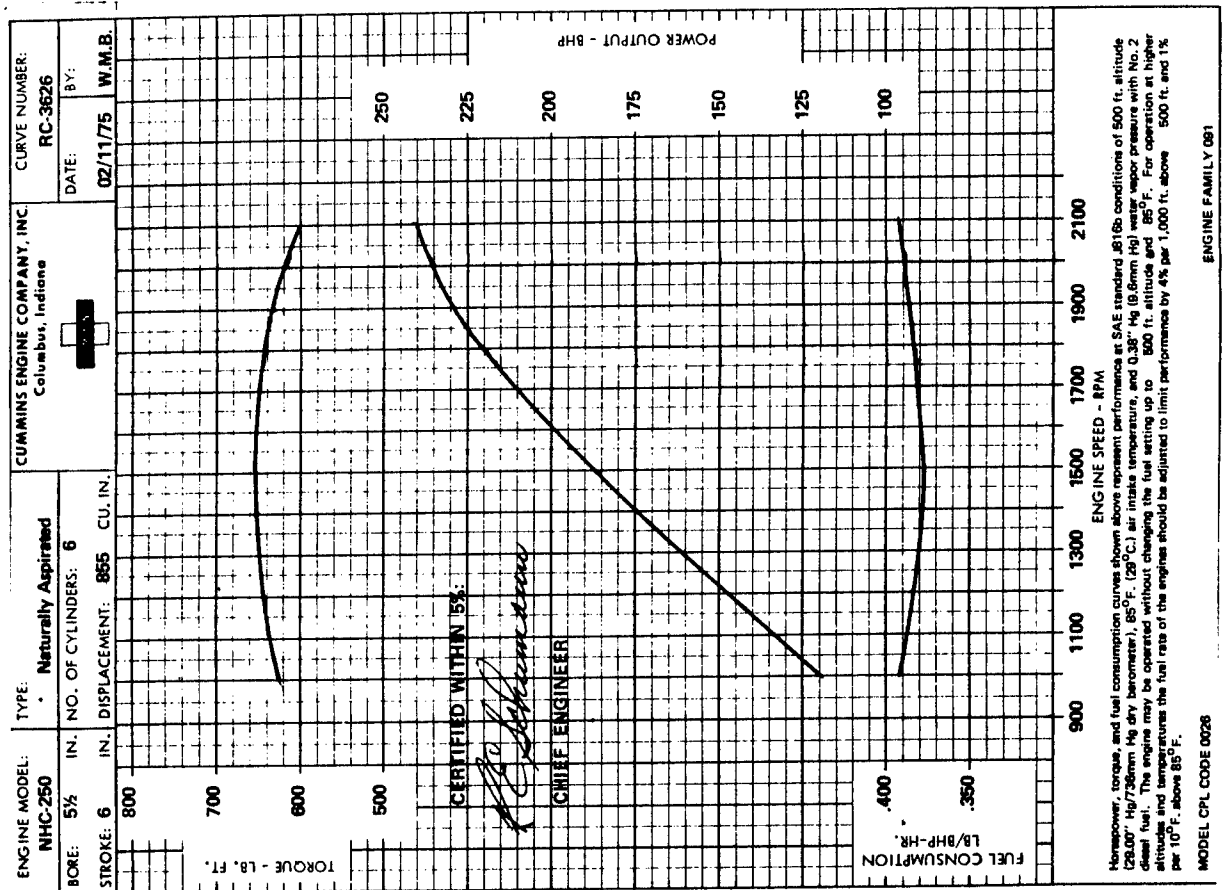


Figure 4-2 Cummins NHC-250 Engine Performance

- **Axle Ratio:**
 - 6.433:1 (AR)
- **Efficiencies:**
 - Engine - 84% (ENEFF)
 - Drivetrain - 90% (DREFF)
- **Tires:**
 - 485 rev/mile
 - Rolling Radius = 20.8 inches (RR)
- **Rolling Resistance:**
 - 26 pound/ton (RES)
 - (good concrete or asphalt)
- **Aerodynamic Resistance;**
 - Frontal Area = 72.8 ft.² (FA)
 - Drag Coefficient, CD = 0.7
- **GVW's:**
 - 35,000 lbs. (cross country)
 - 50,000 lb. (cross country + towed load)
 - 70,000 lbs. (max. highway load)

The predicted performance against the performance goals can be summarized by reviewing the graphical computer output as follows:

- **Highway Goal:** 50 mph on level roadway at 70,000 lb. GCW. Figure 4-3 illustrates that the vehicle can reach 52 mph on a level road with the minimum engine specification.
- **Low-Speed Operation:** Operate at 2.5 mph with engine at max. torque speed range. The engine speed with this gearing is 1447 rpm at 2.5 mph.
- **Grade Operation at 50,000 lbs. GVW:** Ascend a 2% grade at 30 mph. Figure 4-4 indicates that a speed of 36 mph is achievable in 14th gear on a 2% grade with the minimum specification engine.
- **Grade Operation at 35,000 lbs. GVW:** Ascend a 60% grade at a minimum speed of 2.5 mph. From Figure 4-5 it can be seen that a speed of 3.5 mph can be achieved in first gear on a 60% grade with a minimum specification engine.

To give a better understanding of the gradability potential in the lower gears, another computer calculation is made, and a graph of gradability vs. vehicle speed for the first seven gears is shown in Figure 4-6.

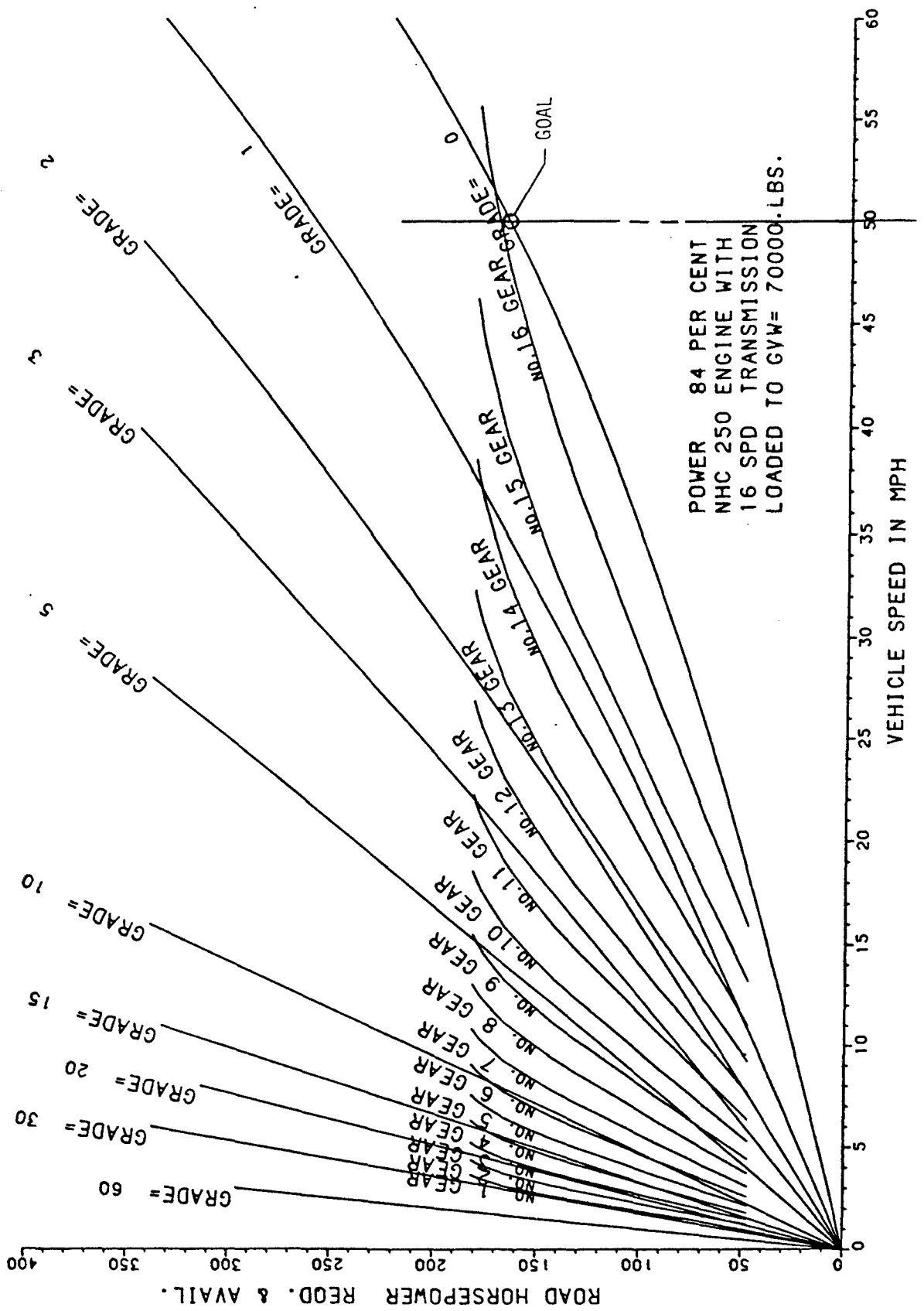


Figure 4-3 Highway Performance

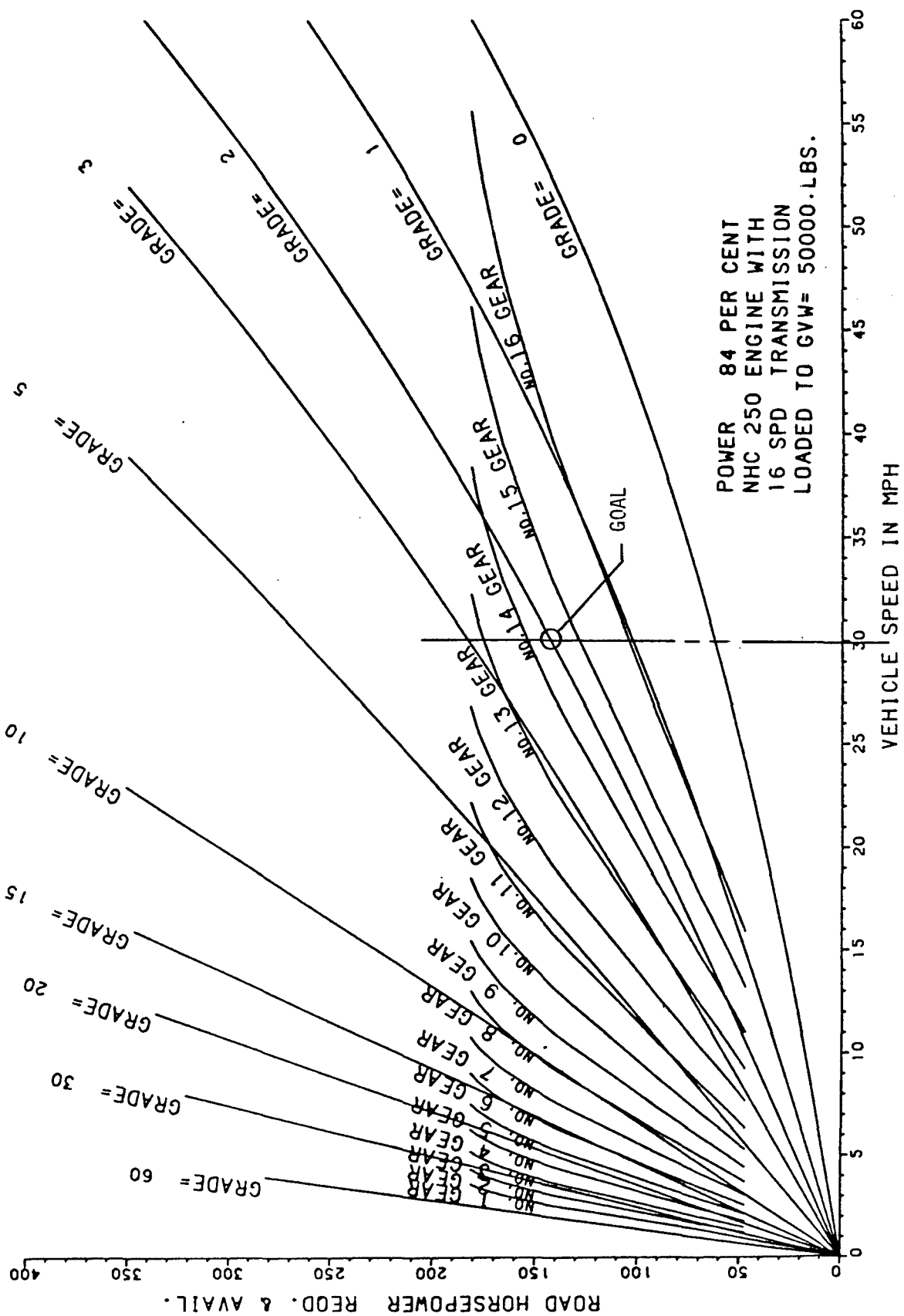


Figure 4-4 Performance at 50,000 lbs

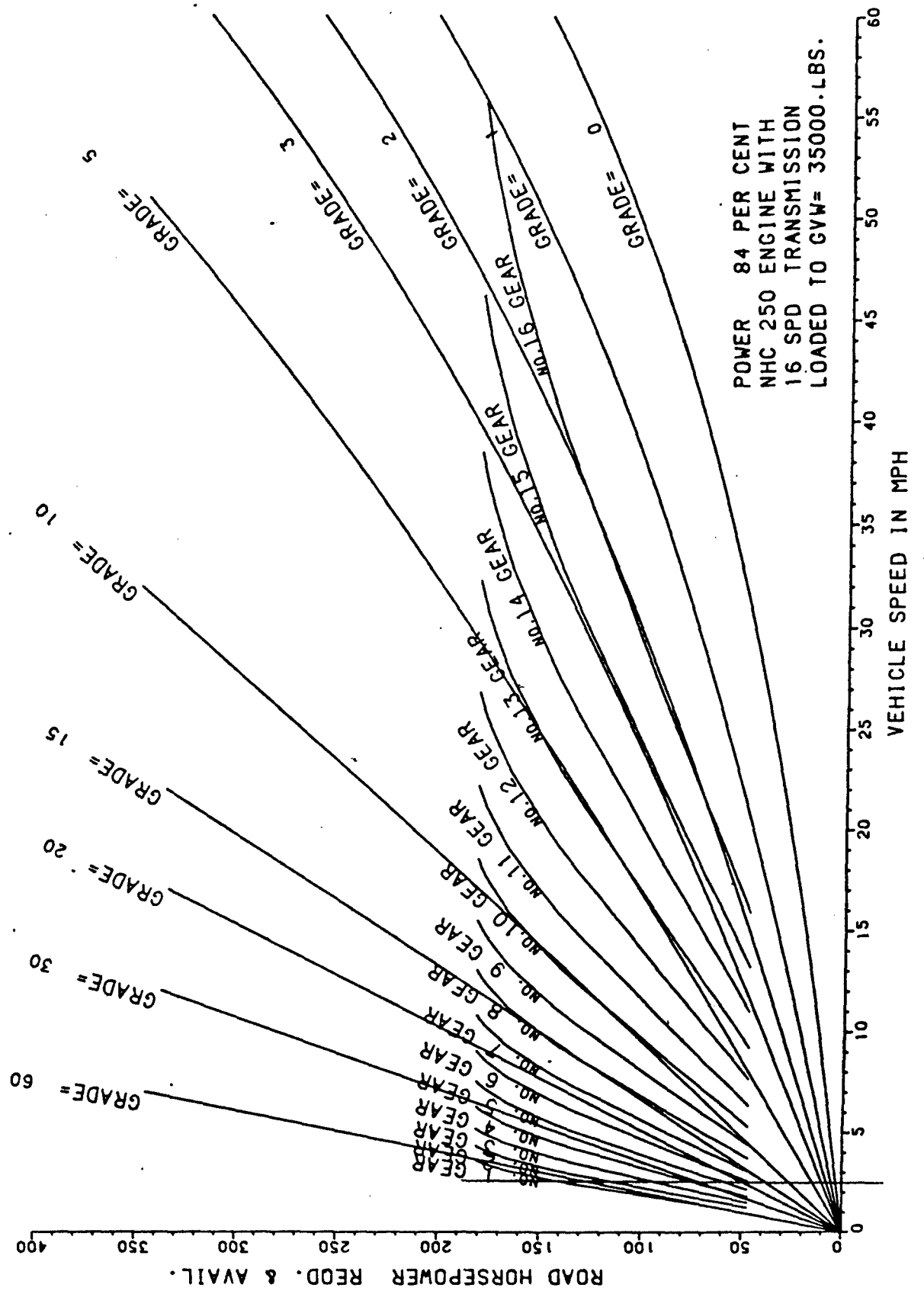


Figure 4-5 Performance at 35,000 lbs.

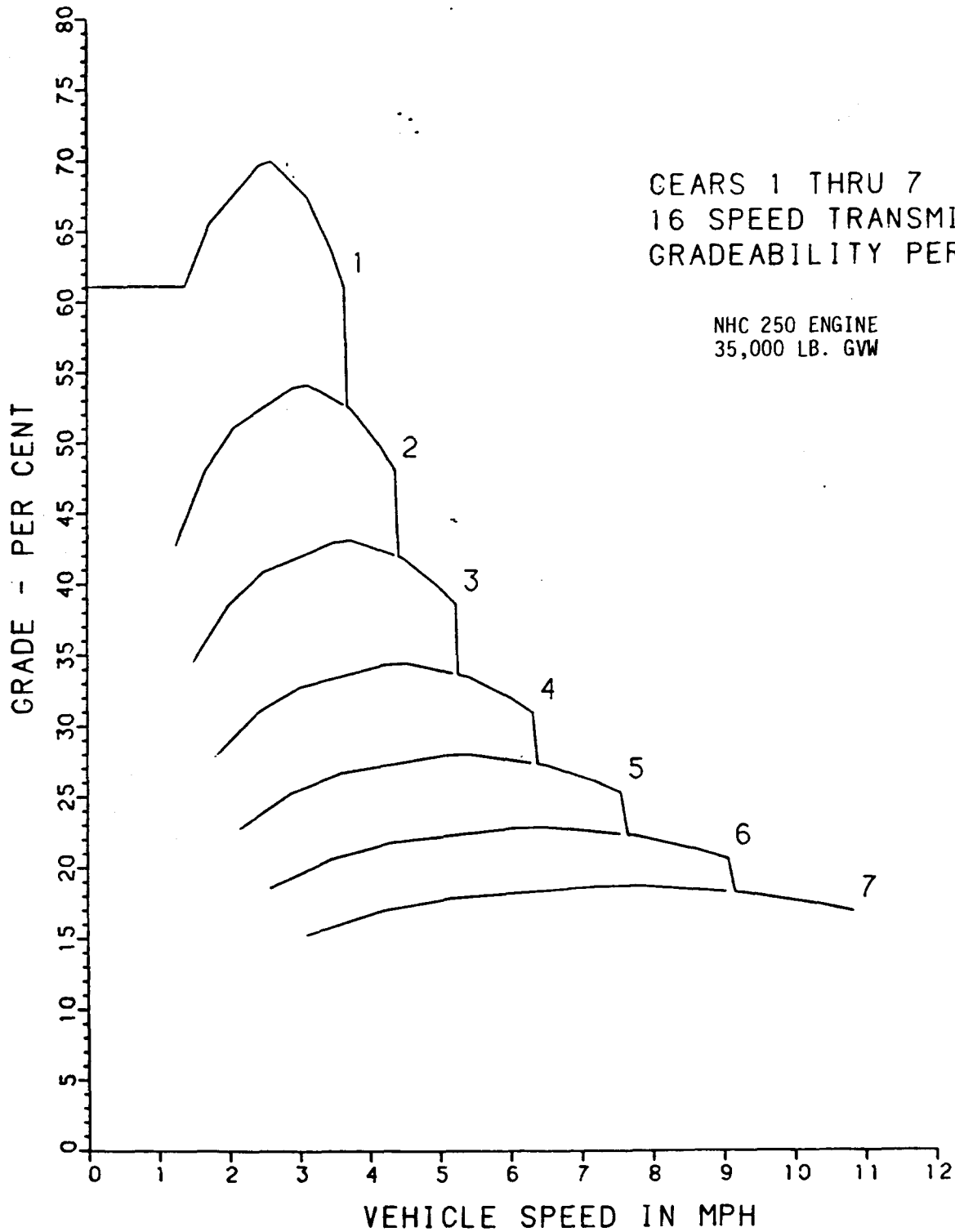


Figure 4-6 Gradeability vs. MPH

Gradability can be defined by the following equations for any rpm or vehicle speed.

$$\text{Gradability} = \tan [\arcsin (\text{ETE}/\text{GVW})]$$

Where:

ETE = Excess Tractive Effort - lbs.

GVW = Vehicle Weight - lbs.

$$\text{ETE} = \text{ATE} - \text{ZTE}$$

Where:

ATE = Available Tractive Effort

ATE = Torque x ENEFF x TR x AR x DREFF x 12/RR

ZTE = Zero Grade Resistance Forces

ZTE = $\text{GVW}/2000 \times \text{RES} + .0026 \times \text{CD} \times \text{FA} \times \text{MPH}^2$

This "gradability" term assumes that all the available tractive effort in excess of the rolling resistance and aerodynamic resistance is available for overcoming the grade calculated.

Again, the engine data used is for the minimum specification engine. From zero to 1 mph the calculation assumes that the clutch will transmit the typical Cummins engine clutch engagement torque of 600 lb-ft at a speed just above idle.

In actual conditions, the torque transmitted during the slipping condition is a function of how much throttle depression is made by the driver, the rate of clutch application and the torque capacity of the clutch.

The electronic control attempts to maintain an engine speed during this slipping mode as a function of the throttle position.

The farther the throttle pedal is depressed, the higher the engine speed and the resulting engine torque would be during the start.

As can be seen from the analysis, the stated performance goals can be achieved with the TSO-11616 gear ratios and a minimum specification engine.

The automated mechanical transmission system described offers benefits over the existing transmission and two-speed transfer case presently used in M939 5-ton army trucks.

Elimination of the torque converter offers:

- higher efficiency
- significantly less heat rejection, which reduces the engine cooling load, radiator size and plumbing requirements
- improved fuel economy

Elimination of the two-speed transfer case by having sufficient reduction in the transmission offers:

- simpler installation by reducing the number of driveshafts from four to two and also eliminating the center bearing mounting.
- better U-joint angles under all conditions of operation.
- potential of lower original equipment cost for the drivetrain system.

The use of an automatic transmission with a high number of ratios and small ratio steps over the entire speed range offers advantages over gathered ratio steps transmission.

- The average available horsepower over the entire operating range of the transmission is higher.
- Optimization of shift points for operating at lower speeds, especially at part throttle, for better fuel economy is easily achieved.
- The frequency of shifting is not of any significance since the driver is not involved.

The less complex mechanical construction in the gear boxes simplifies maintenance and reduces rebuilding cost, but the use of a simpler mechanical construction than existing powershift transmissions increases the level of complexity required in the electronic controller. The demand on the electronic controller for causing and sensing the synchronous engagement of dog clutches will ultimately require the use of a very-fast-processing, 16-bit microprocessor-based controller.

It also should be recognized that using fixed ratio gearing to replace the torque converter creates a requirement for a large number of shifts between ratios to occur in the low-speed, off-road environment. The number of shifts required per mile in off-highway operation is much higher, but the total number of shifts required over the lifetime of the vehicle is comparable to the requirements for a commercial highway truck.

4.3. Specification Sheets

The application of the Eaton Automated Mechanical Transmission for this contract is to meet the United States Army requirements for a 5-ton M939-Series truck. The mechanical transmission to be adapted shall have rated capacity and gear ratios to meet the performance goals and eliminate the requirement of additional gear reduction or multiple speeds in a transfer case.

The specific performance goals can be summarized as follows:

- Fully automatic operation (no clutch pedal).
- Operation without special provisions.
- Operation in the temperature range of +120°F to -25°F without special equipment.
- Operation with an engine of 210-225 observed hp at 2100 rpm and a torque of 550-650 lb-ft observed.
- Highway Operation - the vehicle at 70,000 pounds GCW shall operate at 50 mph on level roadway.
- Low-Speed Operation - the vehicle shall operate at a speed not to exceed 2-1/2 mph with the engine in the maximum torque speed range.
- Grade Operation
 - At a GCW of 50,000 pounds, the vehicle shall ascend a grade of 2% at a speed not less than 30 mph.
 - At a GVW of 35,000 pounds, the cross-country payload without towed load, the vehicle shall ascend a grade of 60% at a minimum speed of 2.5 mph. The grade surface shall be smooth, dry concrete.
 - The vehicle shall demonstrate gradability operations on prepared grades without stalling, overheating or upsetting.

The above is a condensation of the M939 performance goals as outlined in Attachment 1 of the contract DAAE07-82-C-4121. See Table 4-2 for transmission specifications.

4.4. Test Plan at Eaton Proving Grounds

4.4.1. Description of Tests. Prior to delivery of the M939 5-ton truck to TACOM with the TSO-11616 automated mechanical transmission with the integral transfer case, a test plan was drafted and submitted to TACOM for approval. The purpose of the test plan was to verify that the transmission system allowed the performance goals of the M939 5-ton truck to be achieved.

The specific tests conducted were as follows:

- | | |
|-----------------------------|---|
| ● High Speed | Operates at a sustained high speed of not less than 50 mph at 50,000 lbs. GCW. |
| ● Low Speed | Operates at a sustained low speed of not more than 2.5 mph without damage to the vehicle. |
| ● Gradability on 60% Slope | Negotiate a 60% grade at a minimum speed of 2.5 mph. |
| ● High-Speed Gradability | Ascend not less than 2% grade at 30 mph at 50,000 lb. GCW. |
| ● Cruising Range | Operate for not less than 300 miles at an average speed of 30 mph without refueling. |
| ● Cross-Country Operation | The vehicle shall transport rated cross country payload plus towed load over unimproved roads trails, open fields, hills and rough cross country terrain. |
| ● Panic Braking | Vehicle must be braked without stalling engine. |
| ● Shift Performance | Demonstrate and record upshifts on 30% grade, forced downshifts on 30% grade, both in off-road shift mode and also upshifts and downshifts in the highway mode. |
| ● Clutch Protection Circuit | Demonstrate that the clutch will be applied fully to prevent abuse if the improper gear is selected for starting. |
| ● Acceleration Test | Record 0-50 mph time at 35,000 and 50,000 lb. GCW. |

Table 4-2. Transmission Specifications

Rating	Input Torque Transmission with T-Case Transmission w/o T-Case	650 lb-ft 1150 lb-ft
Mounting	Engine Vehicle	SAE No. 1 or No. 2 clutch housing 3-bolt vertical mounting pad each side
Controls	Type	Electronic logic with pneumatic valves for complete automation of clutch and transmission
Clutch	Type Lining	14 in. diameter, 2-plate, pull-type Ceramic
Gearing	Type Overall Ratio Transfer Case Ratio Gear Ratios with T-Case First Second Third Fourth Fifth Sixth Seventh Eighth Ninth Tenth Eleventh Twelfth Thirteenth Fourteenth Fifteenth Sixteenth Low Reverse High Reverse Reverse Overall Ratio	Constant mesh, spur gears 15.34:1 with 16 speeds and 20% steps 0.875:1 11.12:1 9.28:1 7.76:1 6.42:1 5.36:1 4.47:1 3.74:1 3.09:1 2.61:1 2.18:1 1.82 1.51 1.26:1 1.05:1 0.875:1 0.724:1 10.23:1 7.13:1 14.13:1
Oil System	Oil Type Oil Cooler Capacity with T-Case Capacity w/o T-Case	SAE 30 Engine Oil MIL-L-2104C or MIL-L-46152 Optional 20 Quarts 15 Quarts
Dimensions (with T-Case)	Length (w/o Parking Brake) Width Height Weight (dry)	39.08 inches 26.90 inches 26.12 inches 1290 lbs.
Dimensions (w/o T-Case)	Length (w/o Parking Brake) Width Height Weight (Dry)	42.20 inches 21.10 inches 22.63 inches 956.5 lbs.

The above tests were completed during March and April in 1985. After completion of the Aberdeen Proving Grounds test plan, the following tests were redone to verify that the initial capability still existed.

- 60% Gradability Negotiate a 60% grade at a minimum speed of 2.5 mph.
- Panic Braking Engine not stalled
- Acceleration Test

The description of the test plan and the completed data sheets are contained in Appendix B.

4.4.2. Summary of Test Results.

4.4.2.1. Test A – high speed at 50,000 GCW. The test was repeated twice while doing laps around the 1.6-mile oval at Eaton's Proving Ground. The oval has a long grade of approximately 1% on the west side and a short 7% down grade on the east side. On a typical lap the speed range was from 51.7 to 58.7 mph in the 16th gear. The test goal of 50 mph minimum was surpassed.

4.4.2.2. Test B – low speed. The test consisted of driving for 2 miles (48 minutes) at a speed of 2.5 mph, which is a walking speed. A torque converter type transmission may not get out of slip in this speed range and face a significant heat buildup. Without a torque converter, the TSO-11616 automated mechanical transmission would actually cool down because the power loss was lower than the heat loss dissipation due to convection and radiation. At a 50°F ambient, the transmission oil cooled from 125°F to 110°F.

At a 63°F ambient, the transmission oil went from 150°F down to 120°F.

4.4.2.3. Test C – 60% grade tests. It was successfully demonstrated that the M939 could easily stop and restart on a 60% grade. This was done before and after the Aberdeen Proving Ground test.

At a load of 33,325 lbs. GVW, the vehicle could ascend the 60% grade with only the tandem axles being driven.

4.4.2.4. Test D – high-speed gradability. The goal was to demonstrate a minimum speed of 30 mph on a 2% grade at 50,000 lbs. A significantly long 2% grade was not readily available for performance of this test; but by consulting the State of Michigan Highway Department, a 1-mile long 3% grade on US131 at mile marker 44 was identified.

The truck was driven on to the grades at approximately 33 mph and would slow down to 26 to 28 mph and then accelerate to 38 mph.

From previous analysis done as shown by Figure 4-4., "*Performance at 50,000 lbs.*," it can be seen that the calculated speed on a 3% grade was 27 mph in 13th gear, but that this power level on a 2% grade would yield a speed of 36 mph in 14th gear. From this it can be inferred that the 2% gradability at 50,000 lbs was achieved at a speed greater than 30 mph.

4.4.2.5. Test E – cruising range. A 310-mile trip was done in 10 hours and 39 minutes, yielding an average speed of 28.8 mph. For this trip, a total of 49.2 gallons of fuel were used, for an average fuel consumption of 6.3 mpg at a GCW of 50,000 lbs. The test goal was satisfied.

4.4.2.6. Test F – cross-country operation. A cross-country course 3.4 miles long consisting of secondary roads and unimproved trails was laid out. The soil conditions were soft and muddy due to the spring thaw. The course was negotiated with towed load and 49,280 lbs. GVW without concern. The goal was successfully achieved.

4.4.2.7. Test G – panic braking. A series of stops were made on a skid pad from speeds in the range of 10 to 40 mph and on surfaces ranging from wet genite ($\mu = .3$) to dry asphalt ($\mu = .8$). Typically, the clutch will disengage the wheels and transmission from the engine as idle speed is approached and prevent stalling the engine. This leaves the driver with his power steering.

This can only be defeated when the driver depresses both the throttle pedal and the brake pedal simultaneously. In this case, the electronic logic cannot differentiate a starting condition from a braking condition and will not release the clutch. The system relies on the driver throttle pedal input for making the operational decisions.

This test was successfully repeated after the completion of Aberdeen test plan.

4.4.2.8. Test H – shift performance. Upshifting and downshifting on 30% grades were demonstrated and recorded while operating in the off-road shift profiles. On-road shifting was also successfully demonstrated and recorded, as well.

4.4.2.9. Test I – clutch performance circuit. A circuit was added which would only allow the clutch to slip at throttle pedal position greater than 50% for a finite time. On repeated application, the slip time is decreased to prevent excessive heat buildup. This was demonstrated by trying to start a 50,000 lb. vehicle on a 25% grade in 5th gear. Typically, the engine would stall before the tires would slip.

4.4.2.10. Test J – acceleration times. Several runs were made at various conditions of load (see Table 4-3). This was done before and after the Aberdeen Proving Grounds test.

4.5. Aberdeen Proving Grounds Test

4.5.1. Description of Test Plan. The M939-series 5-ton truck, NL097Q, with the TSO-11616 automated mechanical transmission with integral transfer transmission case, was delivered to Aberdeen Proving Grounds on 2 July 1985. A technical feasibility test was run, and it was completed by 2 May 1986.

4.5.2. Summary of Results. A final report was written by Mr. Jerry Yursis of APG and is identified as TECOM Project No. 1-VG-120-939-004, Report No. USACSTA-6389.

The actual test plan run consisted of two major parts: performance and endurance.

The performance tests performed were as follows:

- Acceleration tests
- Brake tests, service and parking
- Drawbar pull tests
- Longitudinal slope operation, 10% through 60% grades
- Side slope operation up to 30%
- Fuel consumption

Table 4-3. Conditions of Load

GVW/GCW	Starting Gear	Average Time Before APG	Average Time After APG
Speed Indicator	--	5th Wheel	Speedometer
21,930	5th	35.76 sec.	--
33,595	3rd	56.10 sec.	--
33,595	5th	54.20 sec.	--
50,150		48.00 sec.	--
32,480	5/3	--	45.8
32,480	5th	--	50.5
32,480	1st	--	50.4

The endurance test cycles used all the different courses at APG to create a 5,000-mile test cycle that was repeated twice, three-quarters of the test without towed load, 32,640 lbs. GVW, and one-quarter with towed load, 47,640 lbs. GCW. The endurance test cycle course distribution is listed in Table 4-4.

4.5.3. Problem Description Solution. The problems encountered during the technical feasibility test are summarized by category in Table 4-5. The categories and notes follow the table.

4.6. Disassembly and Inspection

4.6.1. Master Clutch Description. The master clutch connects the engine to the transmission input. The clutch used in the automated mechanical transmission is a typical heavy-duty truck clutch produced by the Spicer Clutch Division of Dana Corporation, Auburn, Indiana. The model number is AS2-1402SD. It is a 14-inch-diameter, two-plate, pull-type clutch with ceramic metallic friction material. It is the "super-duty" model which has a thicker intermediate plate for greater thermal capacity.

The cover assembly uses an angle spring construction to achieve the pressure plate load. With angle springs, the pressure plate load is an indirect load that is applied through a series of six levers instead of directly on the pressure plate.

The advantages of this type of construction are that the release load is substantially reduced, and the plate load remains constant as the clutch facing material wears.

This construction also allows internal adjustment, and a self-adjusting mechanism is built into the design. The adjuster mechanism, which is a replaceable part of the clutch cover, checks for facing wear every time the clutch is actuated. When the wear of the facing exceeds a predetermined amount, the adjusting ring is actuated by the adjuster mechanism, and the clutch release bearing returns to its normal operating position.

A cutaway view of the Spicer clutch is shown in Figure 4-7.

The specifications and part numbers used are as follows:

Clutch Model	AS2-1402SD
Clutch Plate Load	2,800 lbs.
Release Bearing Load	370 lbs.
Clutch Capacity	1,640 lb-ft.
Cover Assembly	SKC 170-6459
Intermediate Plate	113C-70
Rear Driven Disc	128051-1
Front Driven Disc	128052-1
Input Shaft	2-inch, 10-spline

Table 4-4. Endurance Test Cycle

Course	Without Towed Load		With Towed Load	
	km	mi	km	mi
Paved ^a	566	353	189	118
Belgian block ^b	240	150	80	50
Munson gravel ^c	676	422	11	7
Perryman A	361	225	120	75
Perryman No. 1	961	600	320	200
Perryman No. 2	481	300	160	100
Perryman No. 3	961	600	320	200
Churchville B	2403	1500	801	500
Total	6649	4150	2001	1250

^a Includes 200 miles of cruising range test which is not to be included in the total cycle mileage.

^b 40% Belgian block and 60% gravel loop.

^c Includes 100 miles break-in operation, which is not to be included in the total cycle mileage.

Table 4-5. Technical Feasibility Test/Aberdeen Proving Grounds
Categorization of Problems and Failure

	Problem/Failure	Category
Sensors:	Clutch Position Sensor (2 failures)	Development – Note 1
	Low Pressure Switch (failed)	Development – Note 1
	Speed Sensor (backed-out)	Prototype Component – Note 2
Air Leaks:	Steel Ball in Valve (worked loose)	Workmanship – Note 3
	Gasket (torn on reassembly)	Workmanship – Note 3
Oil Leaks:	Gasket Seepage (several)	Workmanship – Note 3
	T-case Output, Front (failed)	Design Revision – Note 4
	Mechanic Induced	Workmanship – Note 3
Actuators:	Clutch Actuator Rotochamber (failed)	Development – Note 5
	Bellofram Piston Seal (failed)	Component Eliminated by Design
	Solenoid Retaining Nut (loose)	Workmanship – Note 3
	Solenoid Poppet Seats (indented)	Prototype Component – Note 2
Mechanical:	Kick-out in Auxiliary Direct (impacts)	Design Revision – Note 6
	Broken Mainshaft (impact Induced)	Design Revision – Note 6
	Twin Splitter Sensor Jump-out	Design Revision – Note 7
	T-case Front Output Bearing	Design Revision – Note 4
Electrical:	Broken Spade Terminal	Prototype Component – Note 2
	Broken Solenoid Wire at PCB	Workmanship – Note 3
	Broken Solenoid Wire at Coil	Workmanship – Note 3
	Bad Solder Joint for Connector	Workmanship – Note 3
	Resister Overheated (undersized)	Workmanship – Note 3
	Solder PROM's into Sockets Because of Vibration	Design Revision

- Note 1 – Development. The clutch position sensor initially selected was inadequate in the truck transmission environment. Similar failures had occurred in Eaton's commercial development project. The sensor manufacturer eventually provided a sealed packaging that provided the necessary durability.
- Note 2 – Prototype components are those which were only selected for the prototype build. A more durable component in packaging and/or specification would be selected for a production system.
- Note 3 – Workmanship. Nine particular problems can be attributed to workmanship of building a one-off prototype system. The consistency of a production process would minimize the occurrence of these problems.
- Note 4 – Design Revision. This note refers to the rebuild change discussed in Section 4.7.4. Axial loads along the front wheel drive output shaft caused severe loading on the bearing and oil seal damage as well. A bearing with higher axial load capacity minimizes the future occurrence.
- Note 5 – Development. The cover over the master clutch adapter was inadequate to prevent dirt and gravel intrusion. A new cover was built in the field to prevent contamination from entering the rotor chamber rolling diaphragm area and initiating damage.
- Note 6 – Design Revision. Under high torque levels, the direct auxiliary jaw clutch would experience an axial kick-out force that would allow it to kick out of engagement and then re-engage, causing a high impact load. The rebuild configuration is described in Section 4.7.1.3.
- Note 7 – Design Revision. The Twin Splitter transmission uses a synchronizing blocker ring/sensor. When the transmission is automated, this feature is no longer required. The blocker rings were modified in the field to prevent future problems.

4.6.2. The master clutch was disassembled after the tests, and the following observations were made:

- No excessive heating occurred
- No damage to components
- Ceramic pads undamaged
- Self-Adjuster functioning and undamaged
- Very good overall condition

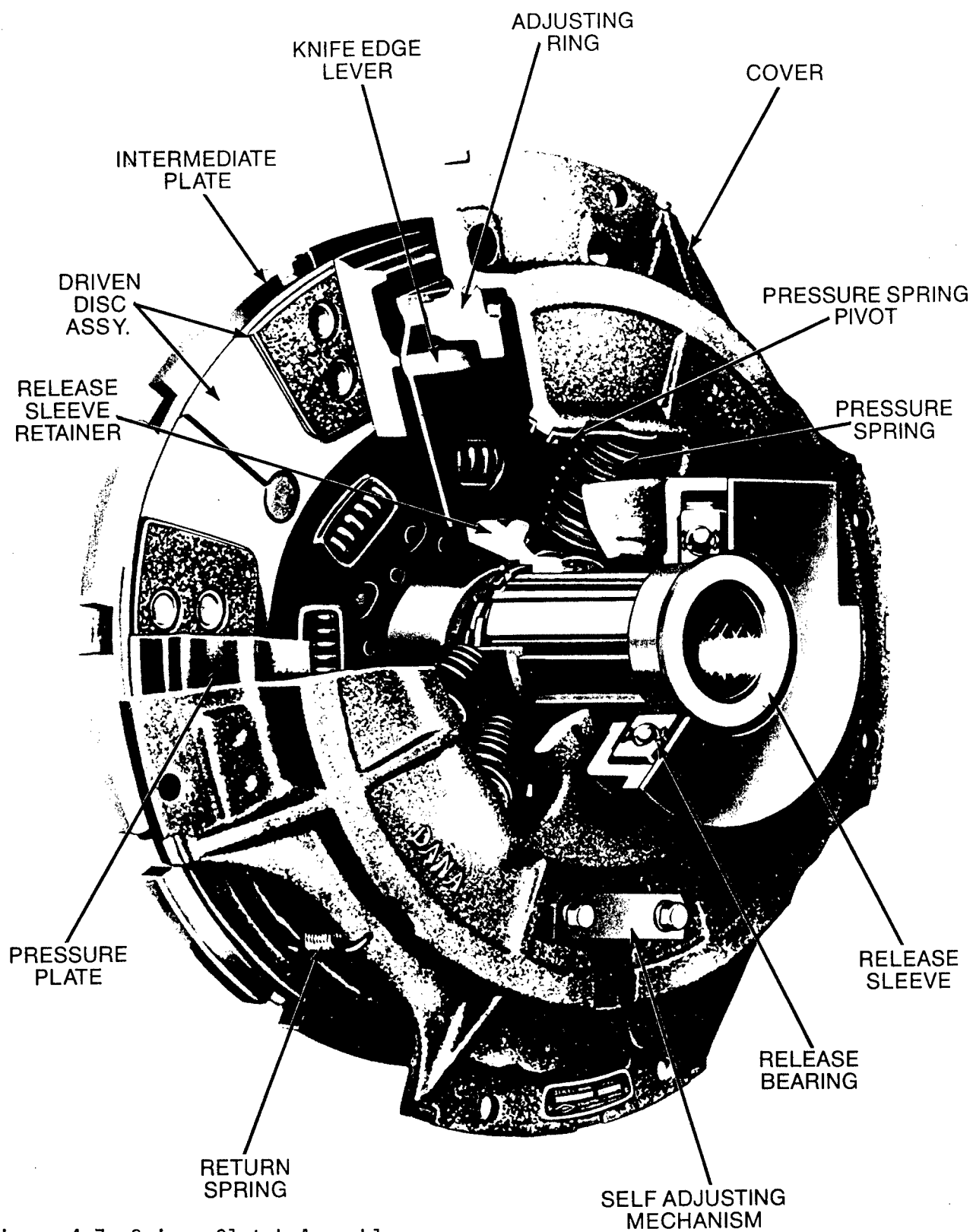


Figure 4-7 Spicer Clutch Assembly

4.6.2.1 . Clutch cycles and mileage. A summary is listed below:

Cycles on Clutch:

TFT - Churchville "B" Course		
4,000 miles x 40 shifts/mile	=	160,000
Munson & Perryman		
6,000 miles x 10 shifts/mile	=	60,000
Highway Miles		
1,000 miles x 4 shifts/mile	=	4,000
Demos and Development		
500 miles x 20 shifts/mile	=	<u>10,000</u>
Estimate of Total Shifts	=	234,000

Miles on Clutch Since Installation:

TFT Test	10,000 miles
Highway Miles	1,000
Demo and Development	<u>500</u>
	11,500 miles

4.6.2.2. Master clutch wear. The wear profile on each cast iron surface was determined using a linear profile machine manufactured by Sheffield. The machine was set so that the length and depth of the profile would be magnified by factors of 10 and 200, respectively. The wear profile was taken radially O.D. to I.D. in four places for each surface. The profiles were then converted by computer to cross sectional wear areas. The average wear was determined by dividing the area by the length of the profile. See the formula below and Figure 4-8.

Profile	=	a trace of wear using a Sheffield linear profiler set for magnified scales
Length	=	length of wear profile
Area	=	Profile converted to cross sectional wear area
Average Wear	=	$\frac{\text{Area}}{(\text{length} \times \text{magnified scale})}$

The friction discs' pads were measured for thickness using a micrometer while the discs were loaded. The loading more closely simulates actual operating conditions. Pad wear can then be determined by subtracting pad thickness used from pad thickness new. Table 4-6 summarizes master clutch wear.

Table 4-6. Master Clutch Wear

Cast Iron Surfaces			Friction Pads		
Plate	Side	Average Wear	Disc	Max./Min.	Average Wear
Intermediate	Front	.0038	New	.360	--
	Rear	.0037	Front	.353/.343	.007/.017
Pressure	--	.0047	Rear	.371/.359	-.009*/.001

* The ceramic material used for the friction pads is a type that expands during the first few applications of the clutch. Pad wear begins after this initial expansion.

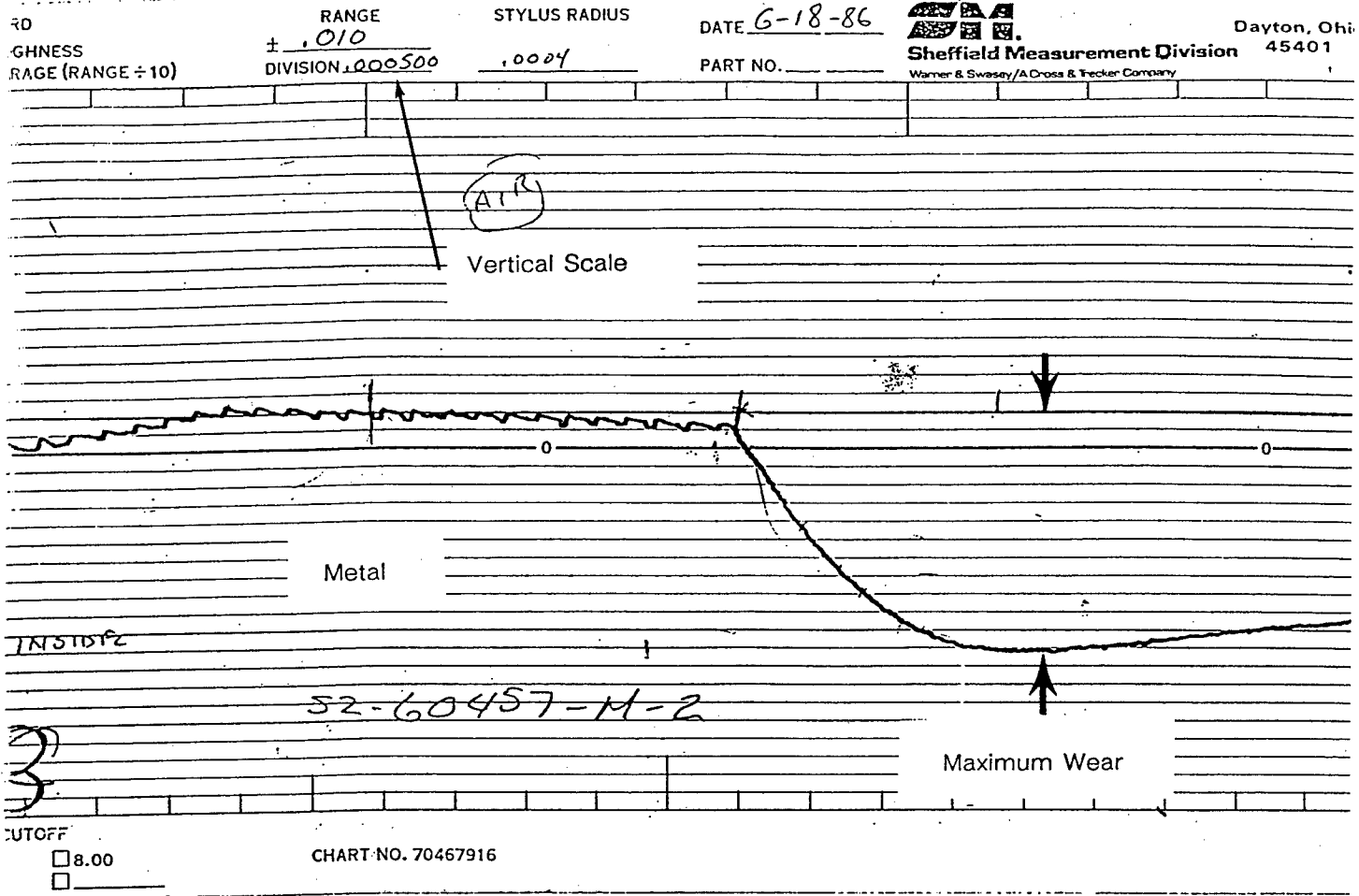
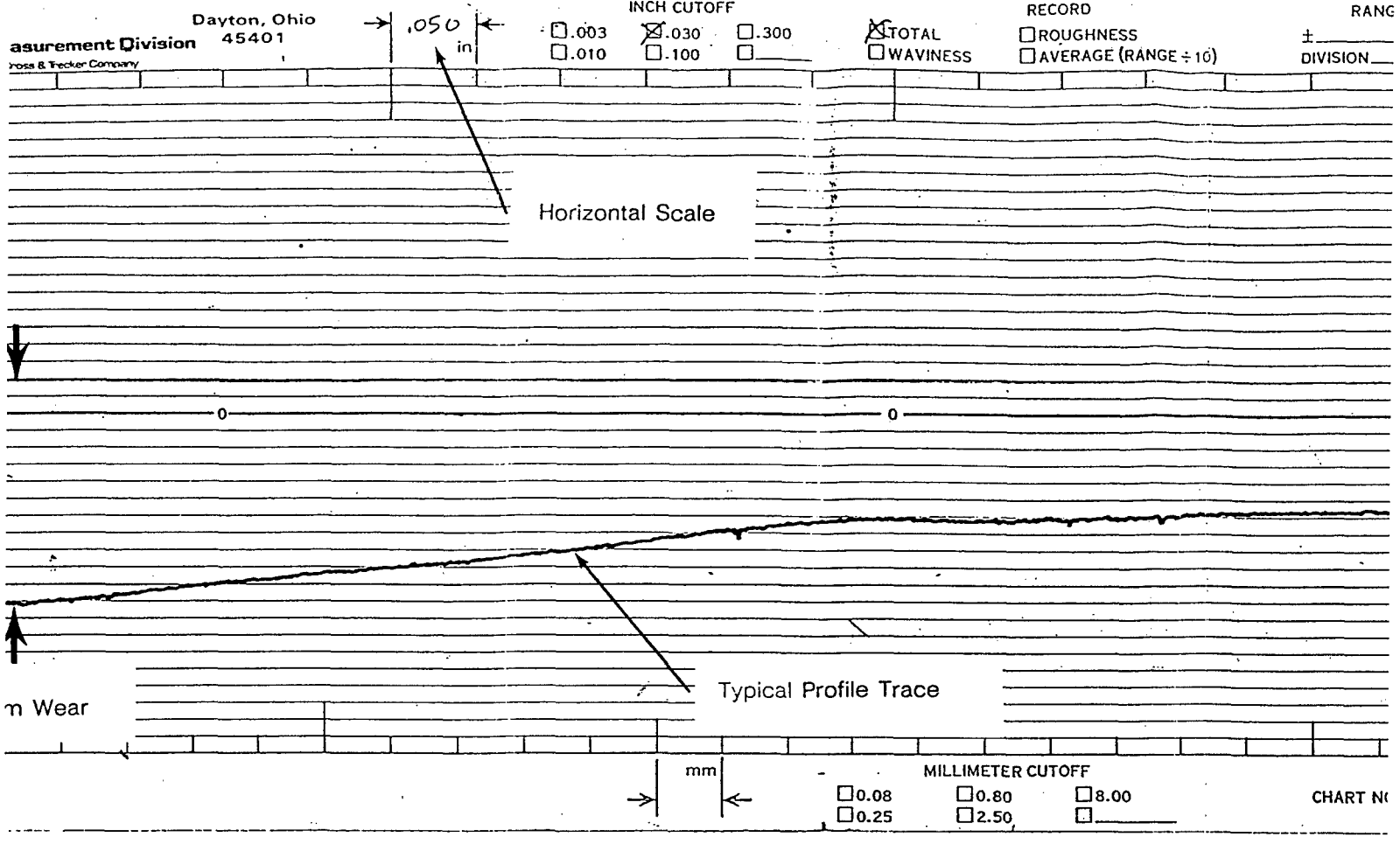


Figure 4-8 Clutch Plate Wear



INCH CUTOFF			RECORD		RANGE		STYLUS RADIUS		DATE	
<input type="checkbox"/> .003	<input checked="" type="checkbox"/> .030	<input type="checkbox"/> .300	<input checked="" type="checkbox"/> TOTAL	<input type="checkbox"/> ROUGHNESS	±					
<input type="checkbox"/> .010	<input type="checkbox"/> .100	<input type="checkbox"/>	<input type="checkbox"/> WAVINESS	<input type="checkbox"/> AVERAGE (RANGE ÷ 10)		DIVISION				PART NO.

Horizontal Scale

Minimum Wear

MILLIMETER CUTOFF			CHART NO. 70467916	
<input type="checkbox"/> 0.08	<input type="checkbox"/> 0.80	<input type="checkbox"/> 8.00		
<input type="checkbox"/> 0.25	<input type="checkbox"/> 2.50	<input type="checkbox"/>		

The clutch was reused as is (see Figures 4-9 through 4-11) during the transmission rebuild for the Modern Technology Demonstration Truck because the wear was found to be minimal. Future wear data will be taken after the new vehicle is tested. This data will help determine clutch life for this application.

4.6.3. Transmission Mechanical Description. The transmission selected to be adapted to meet the M-939 performance goals is the TSO-11616 transmission. This is a twin countershaft design with a four-speed plus reverse front box combined with a four-speed Splitter auxiliary section, for a total of 16 speeds.

The twin countershaft transmission design offers more capacity with less length and weight over single layshaft transmissions.

An important feature of Fuller twin countershaft transmissions is the floating mainshaft. This allows for a 50/50 torque split between the two countershafts and optimizes their gear life.

The TSO-11616 transmission is defined by the following assembly drawings:

- 56336-E, Sheet 1, Full-Size Cross-Section of Main and Auxiliary Section (Figure 4-12.)
- 56336-E, Sheet 2, 1/2-Size Cross-Section of Transmission and Integral Drop Box (Figure 4-13.)
- 56336-E, Sheet 3, 1/2-Size Exterior View of Transmission (Figure 4-14.)

The TSO-11616 transmission, bearings and shafts are designed for an input torque of 1,150 lb-ft. Since in this application the maximum engine torque is only 650 lb-ft. and the rated engine rpm is 2100 rpm, the main box gearing and bearing lives were not recalculated for the lesser inputs.

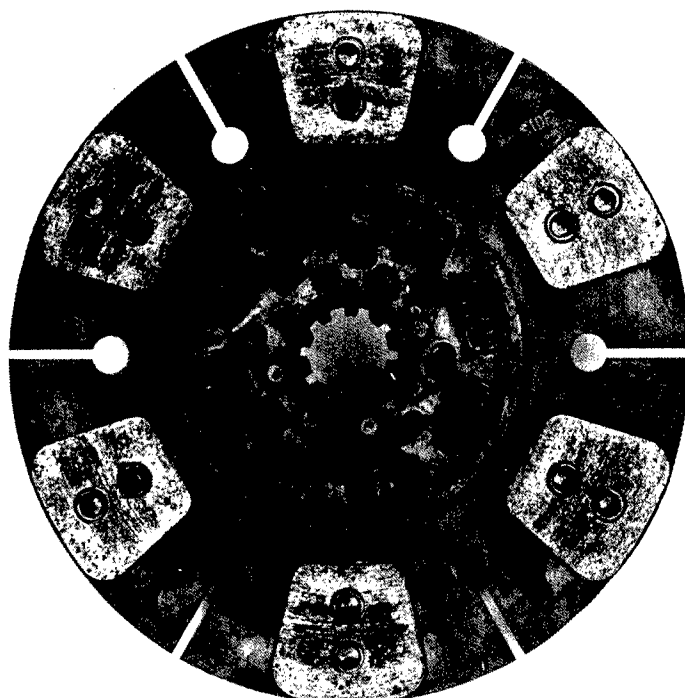
In order to eliminate the transfer case requirements, an integral drop box was added to the TSO-11616 design. This design drops the output shaft 11.62 inches from the engine centerline and moves the output over 9.58 inches towards the left side of the vehicle.

This is comparable to the output positions of the existing transfer case, but is located forward of the original providing better driveline angles and reducing the number of drivelines from four to two.

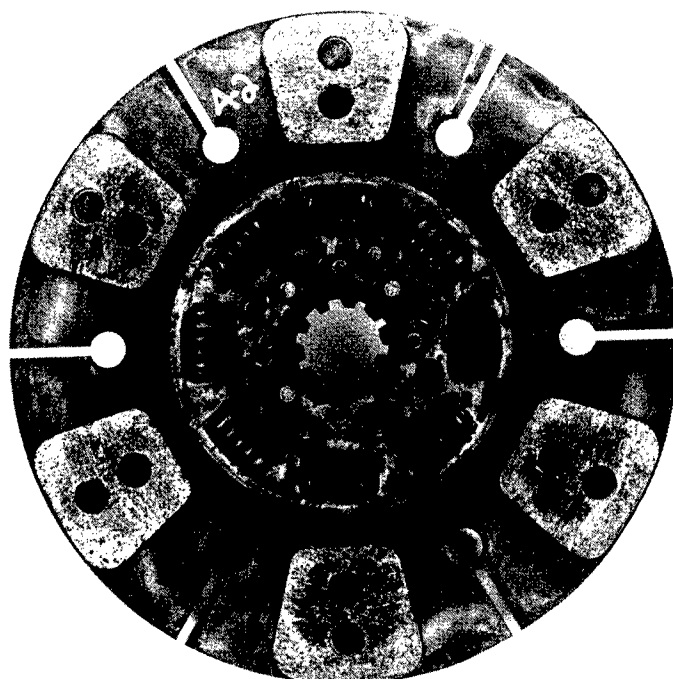
A Curvic Coupling jaw clutch is used to allow the front axle to be disengaged in highway driving. An output driven gear pump is added to improve oil circulation and provide headset lubrication in extended grade operation.

4.6.3.1. Gear inspection. The gears were visually inspected for signs of excessive compressive stresses. Typical compressive stress problems appear on the teeth in the form of frosting, pitting and spalling. All gears were in excellent condition and did not exhibit any compressive stress problems, as shown in Figures 4-15 through 4-18.

The gears were also magnafluxed and inspected for bending fatigue cracks in the roots of the teeth. The overdrive gear on one auxiliary countershaft was found to have nine cracked teeth. Metallurgical analysis determined that the cracks were the result of low to minimum tooth case depth, and core hardness possible produced during the welding process that is used to attach the gears to the countershafts (see Appendix C). The remaining gears were found to be crack-free. All welds used to attach the gears to the countershafts were inspected and found to be crack-free.

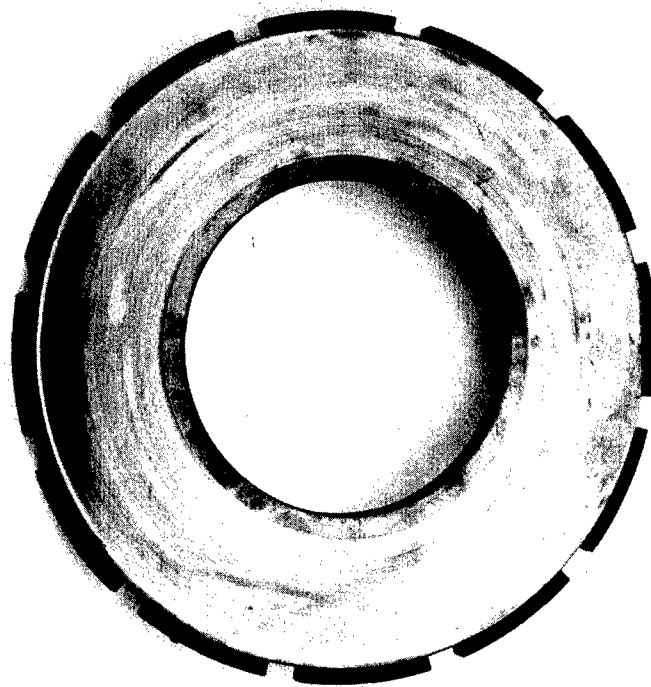


Front

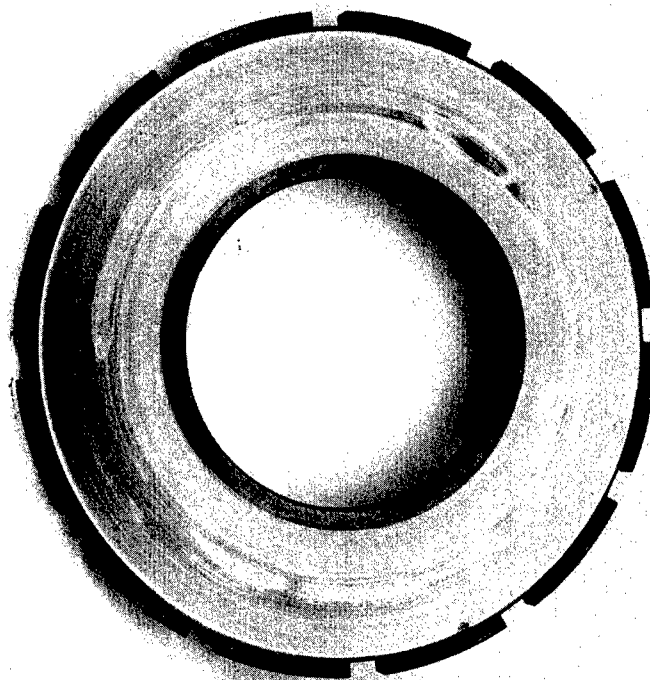


Rear

Figure 4-9. Front Friction Disc

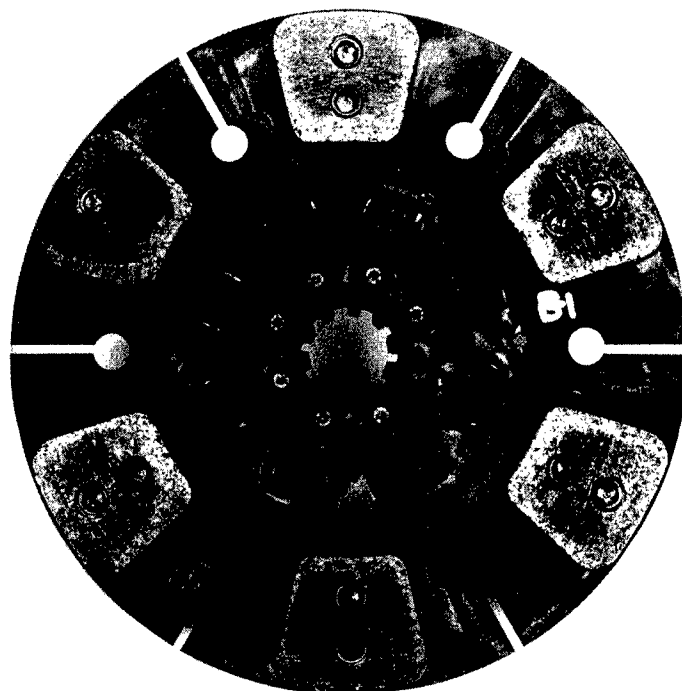


Front

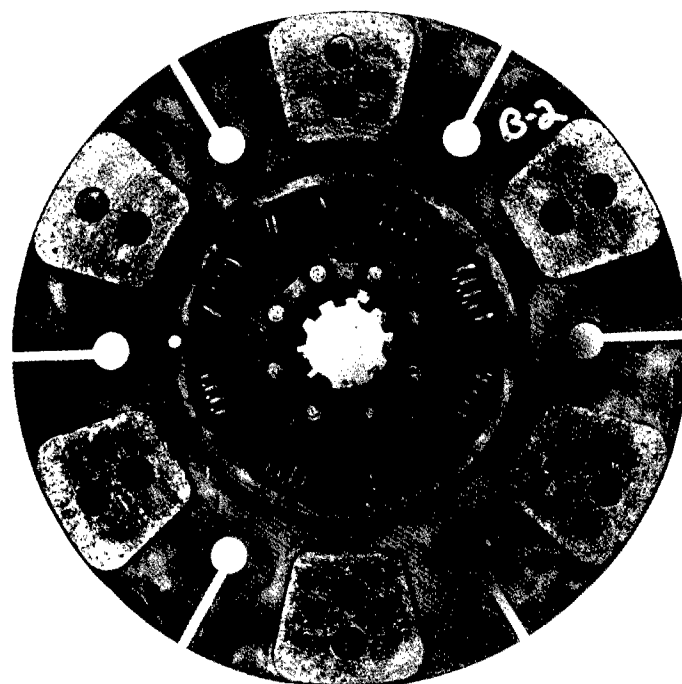


Rear

Figure 4-10. Intermediate Plate



Front



Rear

Figure 4-11. Rear Friction Disc

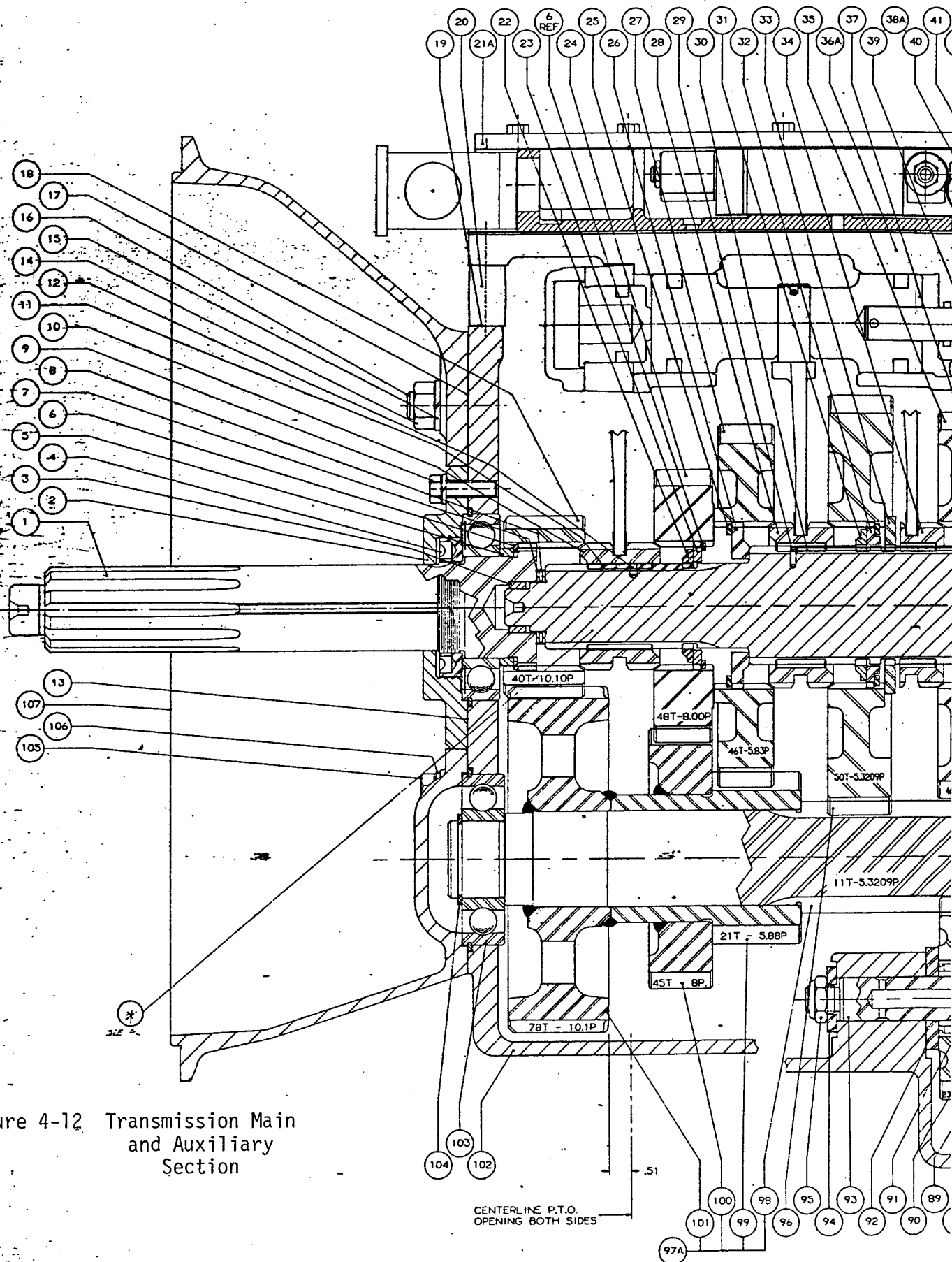
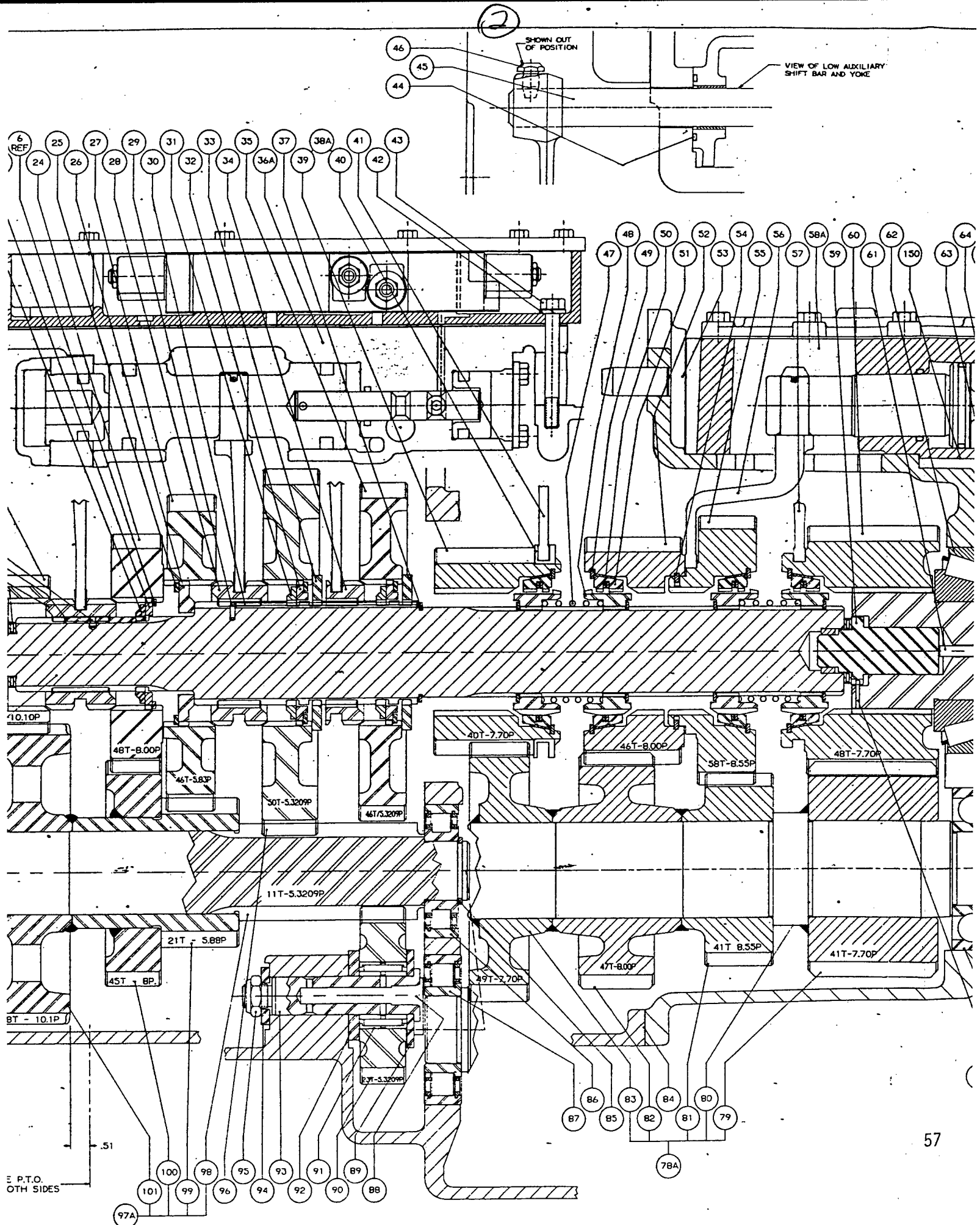


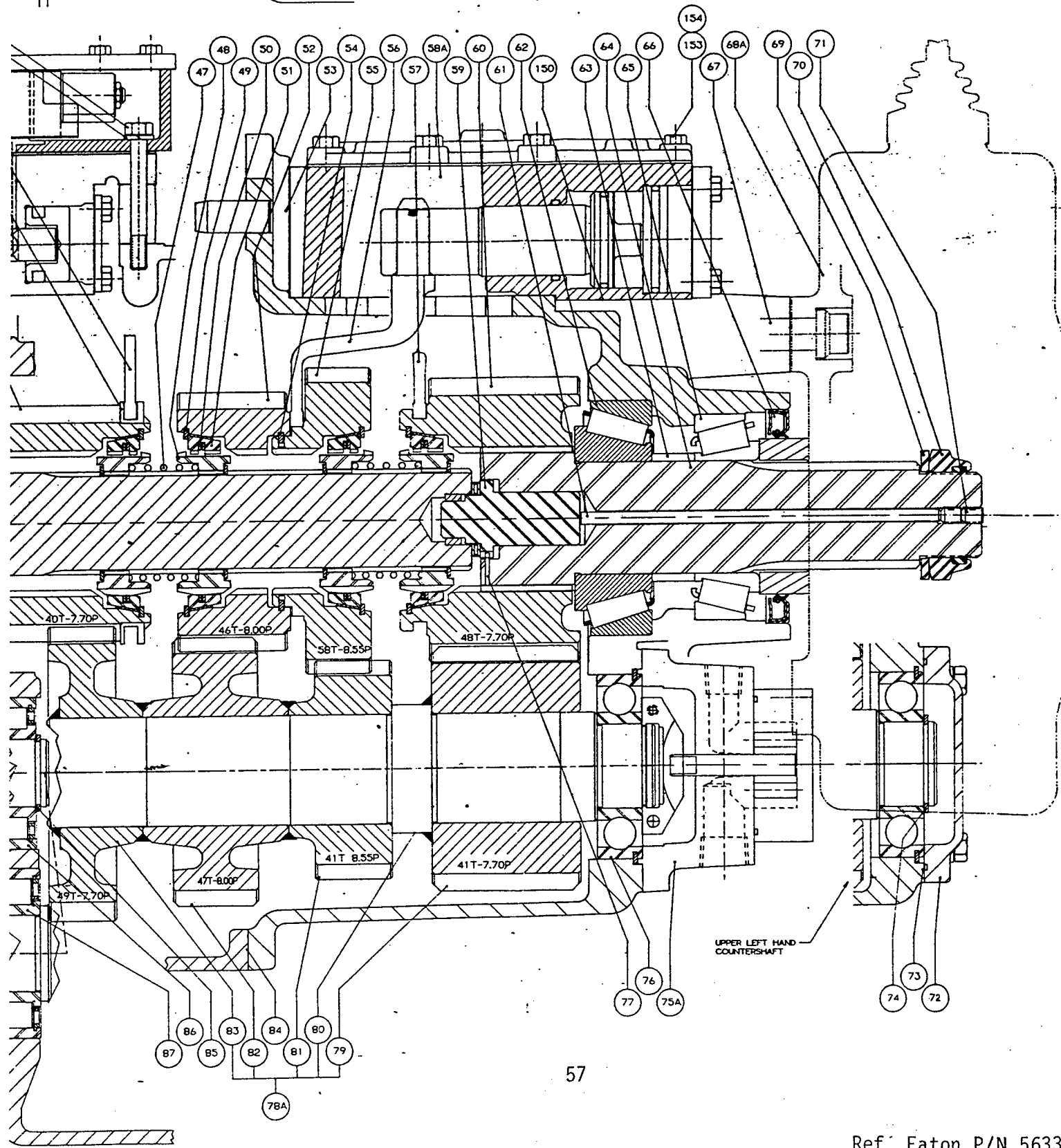
Figure 4-12 Transmission Main and Auxiliary Section



3

SHOWN OUT
OF POSITION

VIEW OF LOW AUXILIARY
SHIFT BAR AND YOKE



①

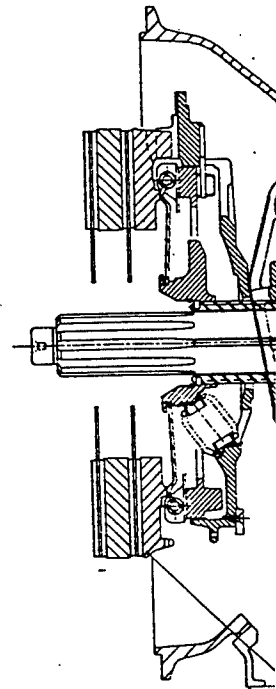
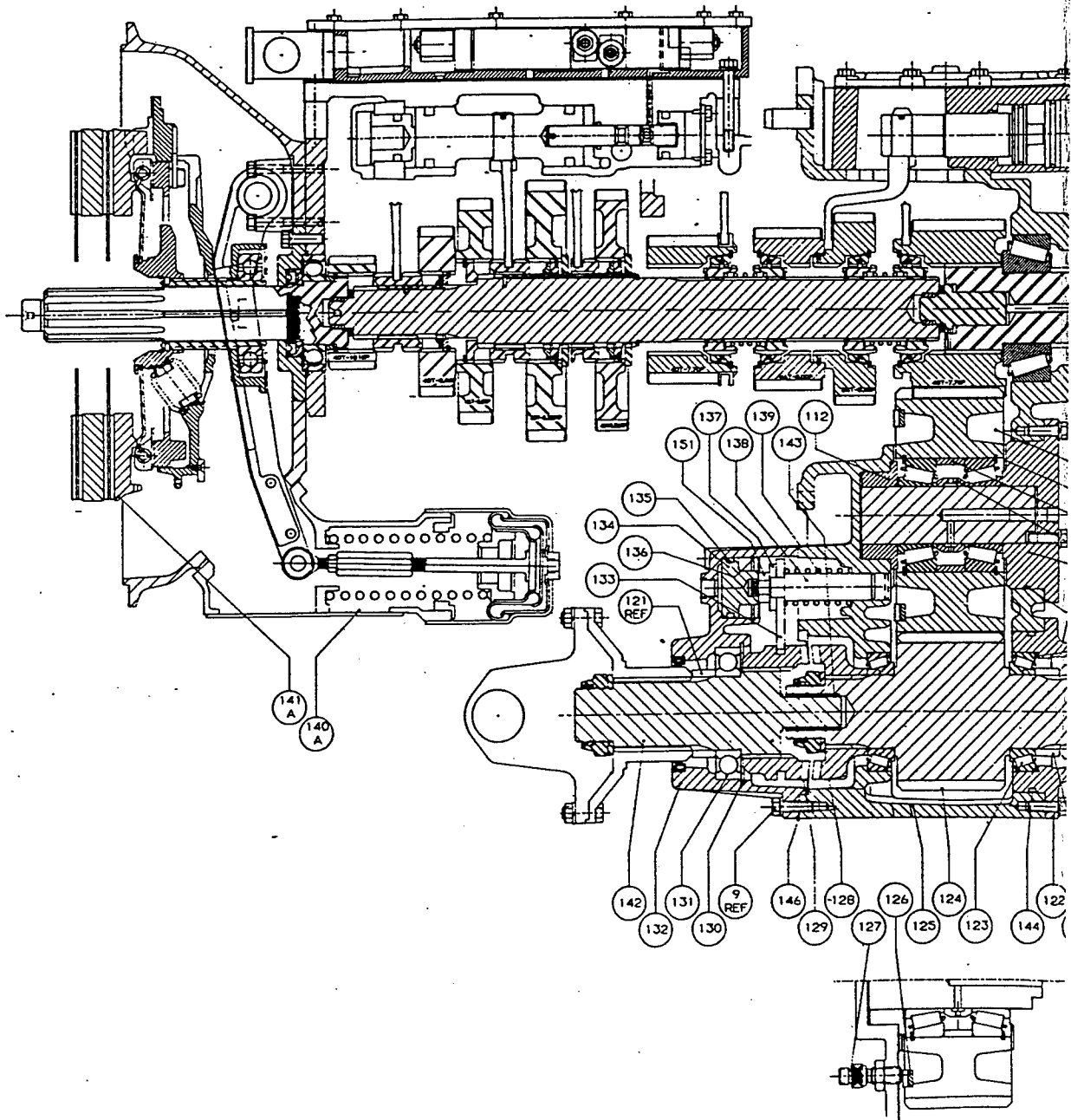
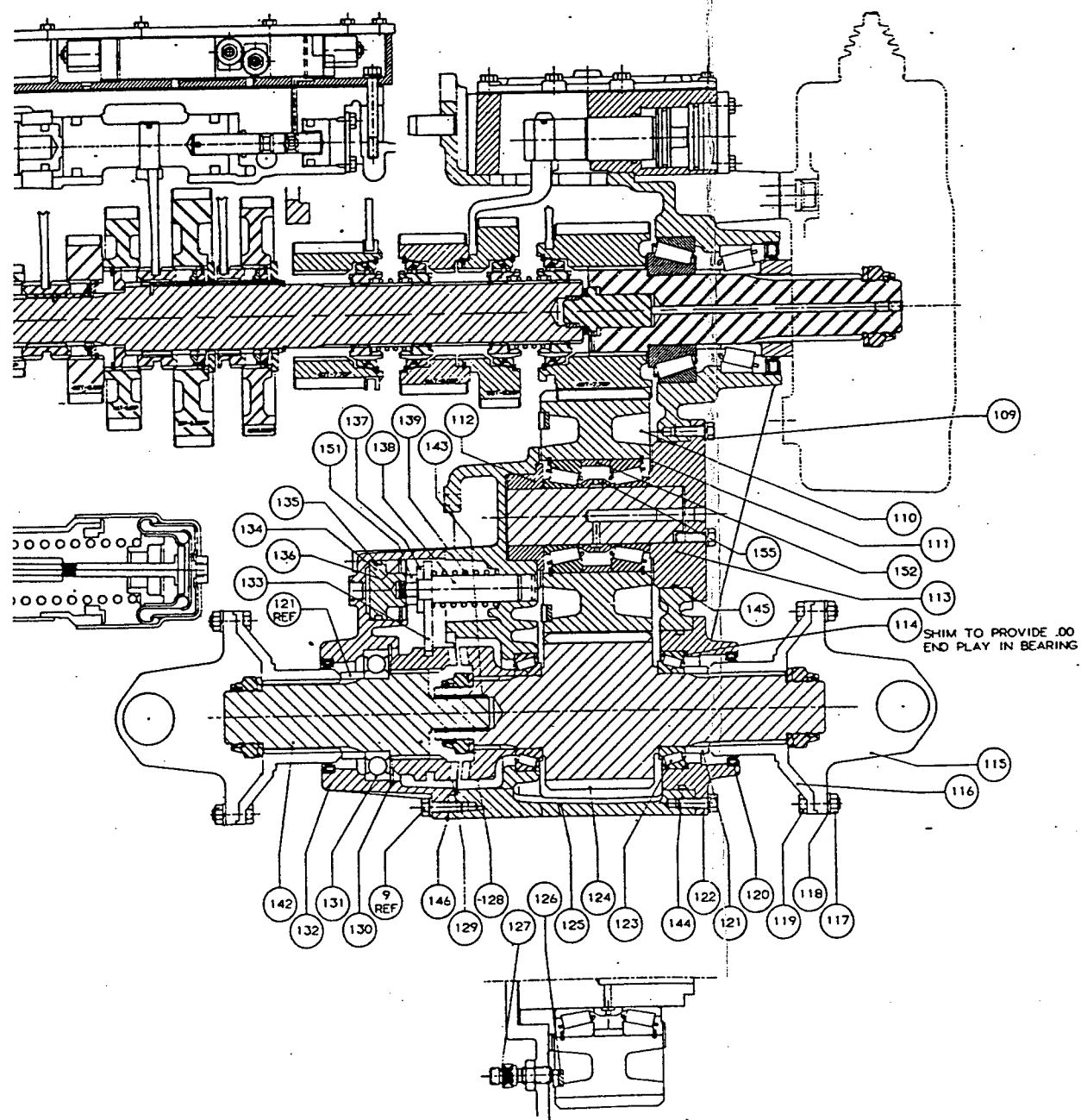


Figure 4-13 Transmission and
Integral Drop Box.

(2)





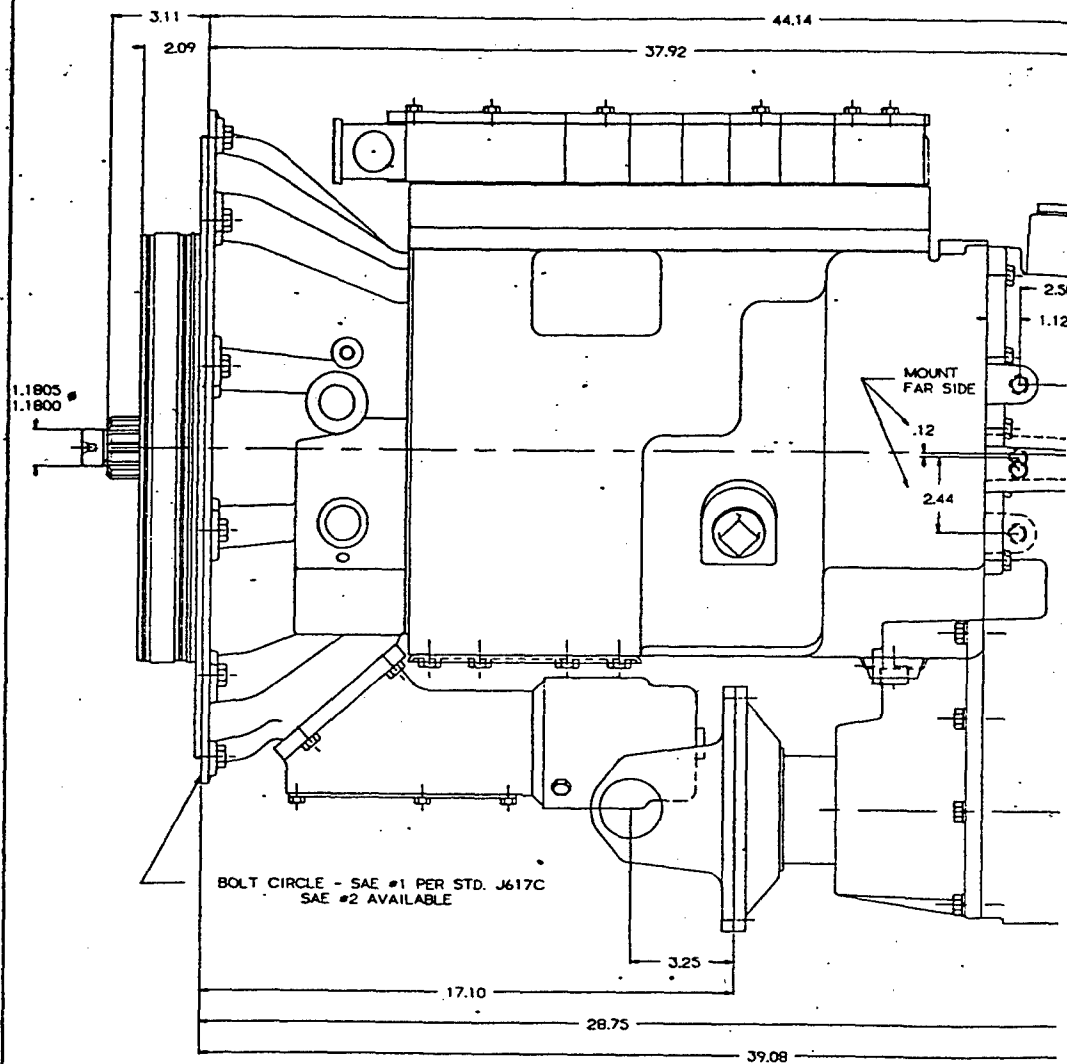
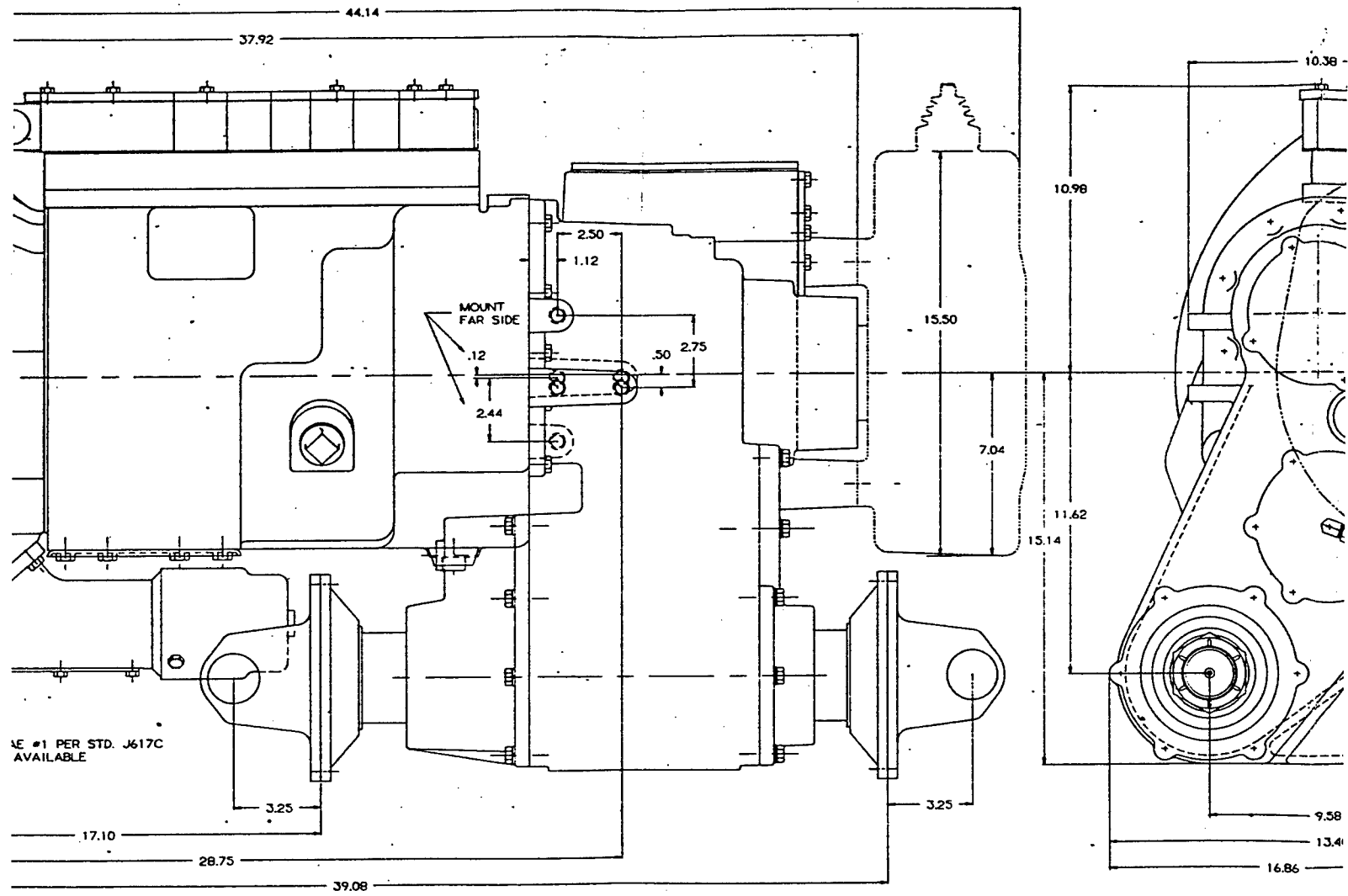
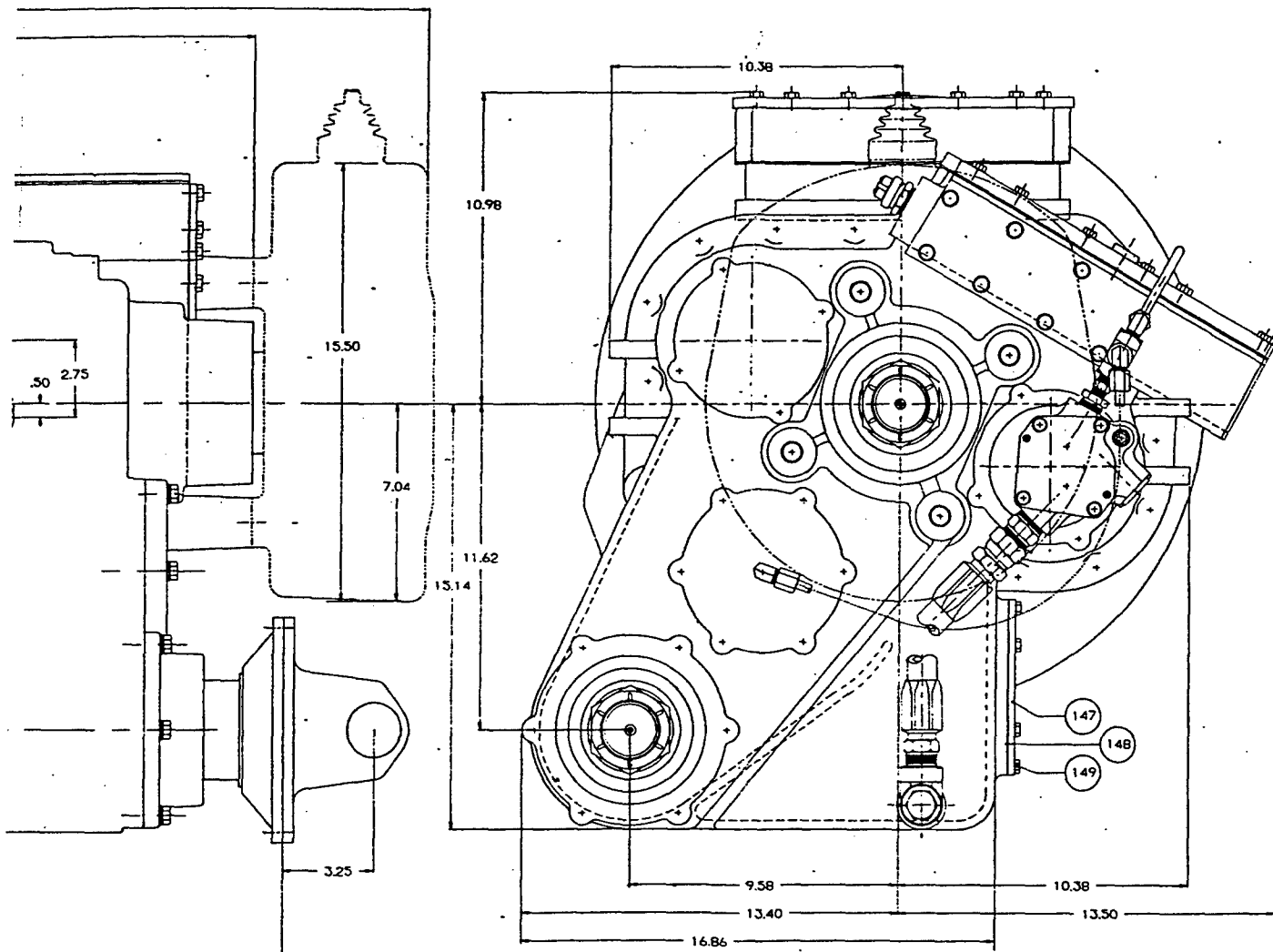


Figure 4-14 Exterior View of Transmission

2



3



Written By D. KRZYSIK	Page 1 Of 10	PL- 56336
Checked By J. DAMON	Project Number 4071-02	
Date Written 7-6-83	Fixture Number	
		PL Page Revision Date

*INDICATES ERC DRAWINGS

Item No.	Part No.	Drawing		PL	Used	Name	Qty.	Remarks
		Size	Rev	Rev	Item			
	56336*	R				TRANSMISSION TSO 11616 MODEL TACOM	3 SHEETS	
1	50473*	D	C			SHAFT - INPUT	1	
2	15111	B				FRONT BEARING COVER	1	
3	18084	B				BUSHING - MAINSHAFT PILOT	2	
4	8997	C				NUT - BEARING DRIVE GEAR	1	
5	16396	B				SPACER - GEAR, MAIN DRIVE	1	
6	14289	C				SNAP RING	2	
7	18097	B				THRUST BEARING RACE	4	
8	18096	B				THRUST BEARING	2	
9	X-8L-604	B				SCREW AND WASHER ASS'Y - HEX HEAD 3/8-16 X 1-1/4"	28	
10	18747	B				CLUTCH - (3-4 GEAR) MAINSHAFT SLIDING KEY- RECTANGULAR, MAINSHAFT (3-4 CLUTCH)	1	
11	A-3456	B					1	
12	14832	B				PIN - KEY, MAINSHAFT	1	
13	14311	C				GASKET - FRONT BEARING COVER	1	
14	X-1-1000	A3				NUT - HEX (5/8-18)	6	SAE GRADE 5
*	54249	D				MAIN SHAFT	1	

Engineering Parts List

E.T.M. Engineering &
Research Center
Southfield, Michigan

Engineering & Research Center Southfield, Michigan										Engineering Parts List			Written By D. KRZYSIK		Page	2	Of	10	PL- 56336
										Checked By J. Damau		Project Number 4071-02							
										Date Written 7-6-83		Fixture Number		PL Page Revision Date					
Item No.	Part No.	Drawing		PL	Used	Name		Qty.	Remarks										
		Size	Rev	Rev	Date	Item													
15	X-3-1000	B					LOCKWASHER (5/8 SAE STD. REGULAR)	6											
16	14554	B					STUD - 5/8	6											
17	14310	D					GASKET - HOUSING CLUTCH	1											
18	54586*	C	B				GEAR - (MAIN DRIVE)	1											
19	54944*	D					GASKET (SHAFT BAR HOUSING)	2											
20	56804*	D					SPACER - AIR VALVE MANIFOLD	1											
21A	54982*	D					AIR VALVE MAINFOLD ASS'Y	1		(SEE PL-54982)									
22	TAB IN REMARKS C						GEAR WASHER (MAINSHAFT SELECTIVE)	1		F14274, F14275, F14276, F14278, F14279, F14277									
23	14273	C					SPACER (SPLINED MAINSHAFT GEAR)	1											
24	54587*	D	B				GEAR (MAINSHAFT 3RD)	1											
25	16798	B					SNAP RING	3											
26	18317	C					SPACER (2ND GEAR) - SPLINED GEAR, MAINSHAFT	1											
27	54588*	D	C				GEAR (MAINSHAFT 2ND)	1											
28	18316	B					MAINSHAFT SLIDING - CLUTCH (1-2 GEAR)	1											
29	62504						ROLL PIN (KEY STOP) 1/8 X 7/16	1		(59-028-125-0437)									
30	55488*	B	B				KEY - MAINSHAFT GEAR	1											

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Item No.	Part No.	Drawing Size	PL Rev	Used Item	Name	Cty.	Remarks
	TAB IN						
31	REMARKS C				WASHER - SELECTIVE MAINSHAFT GEAR	2	F18334, F18335, F18336, F18337, F18338, F18339
32	18318 C				SPACER - SPLINED MAINSHAFT, GEAR	2	
33	18322 C				WASHER - MAINSHAFT REV. GEAR, REAR	2	
34	50498* B A				CLUTCH - REV. GEAR	1	REF MAKE FROM 18316
35	55676* D B				GEAR - MAINSHAFT REVERSE	1	
36A	56830* E				AIR SHIFT - ASS'Y	1	(SEE PL- 56830)
37	18113 B				MAINSHAFT - SNAP RING	5	(XAN-275)
38A	54963* D A				GEAR - MAINSHAFT ASS'Y	1	
39	54232* D C			38A	GEAR - MAINSHAFT LOW, AUX.	1	
40	54962* D A			38A	COLLAR - GEAR	1	
41	56712* D				YOKE - SHIFT, LOW	1	
42	—				LOCKWASHER (3/8 SAE STD. REGULAR)	22	
43	—				HEX. HEAD BOLT 3/8-16 x 3	16	
44	—				O'RING (1-1/2 x 1-3/4 x 1/8)	1	PARKER #2-222
45	56737* D				BAR - AUX., LOW SHIFT	1	
46	15776 B				SHIFTING YOKE LOCKING SCREW	1	

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47	50556*	A				SPRING - MAINSHAFT CLUTCH	2	
48	50554*	D	C			CLUTCH SNAPPER	4	
49	18517	B	C			SNAP RING - SENSOR RETAINING	4	
50	18063	C				RING - PRE-ENERGIZER	8	
51	50555*	D				SENSOR - 1ST, 2ND, LOW INT & OUTPUT	4	
52	53900*	D	C			GEAR - MAINSHAFT INTER. AUX.	1	
53	14334					DOWEL TRANS. CASE	2	
54	15228	B				SNAP-RING, INTER. TO O.D. GEAR	1	
55	54233*	D	D			GEAR - OVERDRIVE MAINSHAFT	1	
56	56713*	D				YOKE - SHIFT, INTER. & O.D.	1	
57	56714*	D				YOKE - SHIFT, DIRECT	1	
58A	56675*	E				AUXILIARY SHIFT CYLINDER ASS'Y	1	(SEE PL-56675)
59	50492*	B	C			SUPPORT - MAINSHAFT	1	
60	56776*	D				GEAR - MAINSHAFT OUTPUT	1	
61	56811*	B				ROD - MAINSHAFT SUPPORT ADJUSTING CUP H715310	1	
62	---					BEARING - TAPERED ROLLER CONE H715343	1	TIMKEN

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Item No.	Part No.	Drawing Size	Rev	PL Rev Date	Used in Item	Name	Qty.	Remarks
63						SPACER - BEARING, BRAKE OUTPUT	1	TO BE SUPPLIED BY TIMKEN
64	56775*	D				SHAFT - OUTPUT	1	
65						CUP HM212049 BEARING - TAPERED ROLLER CONE HM212010	1	TIMKEN
66						OIL SEAL #36363 (3-5/8 x 5 x 7/16)	1	CHICAGO RAWHIDE
67						CAP SCREW 12 PT (3/4-10 X 3)	4	FERRY SCREW CO.
68A						BRAKE - SERVICE (11 X 8) #36525	1	AUTO SPECIALTIES MFG. CO.
69	16337	B				WASHER	4	
70	11956	C				NUT - HEX, NYLON INSERT (2-16)	4	
71	56314*	B				SET SCREW (3/8-16 X .50)	2	
72	18094	B				AUX. COUNTERSHAFT BEARING COVER	1	
73	18107	B				O'RING - AUX. C'SHAFT, REAR BEARING COVER	1	
74						SNAP RING #1065R	1	EATON ENG. FASTENERS
75A						PUMP KIT #921-S	1	EATON FULLER TRANS.
76	81523					BALL BEARING - REAR AUX. C'SHAFT	2	CHART DWG. #81500
77	62502					ROLL PIN - (3/32 DIA. X 3/4 LG)	1	(59-022-094-0750)
78A	56809*	D				COUNTERSHAFT ASS'Y - AUX. WELDED	2	

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Item No.		Part No.		Drawing Size Rev.		PL Rev. Date		Used in Item		Name		Qty.		Remarks							
79		56774*		C				78A		OUTPUT GEAR - AUXILIARY COUNTERSHAFT		2									
80		56773*		D				78A		COUNTERSHAFT		2									
81		53924*		C	C			78A		SPLITTER GEAR - AUX. C'SHAFT OVERDRIVE		2									
82		53925*		C	A			78A		SPLITTER GEAR - AUX. C'SHAFT INTER.		2									
83		53926*		C	A			78A		SPLITTER GEAR - AUX. C'SHAFT LOW		2									
84		57032*		D						GASKET - HSG TO DROP BOX		1									
85		14317		B						SNAP RING		2									
86		14366		B						BEARING - ROLLER, C'SHAFT REAR		2	(HYATT R-1308-TS)								
87		—								BEARING - ROLLER, AUX. C'SHAFT FRONT		2	(HYATT R-1309-TS)								
88		5202		B						STRAIGHT PLUG 1/2-13 USS HOLE		2									
89		56125*		C	A					WASHER CUP - REVERSE IDLER		2									
90		55677*		C	C					GEAR - REV. IDLER		2									
91		—								BEARING - REVERSE IDLER GEAR		2	HJ202820 TORRINGTON IRI62020								
92		56177*		B						WASHER - THRUST, REVERSE IDLER		2									
93		55936*		C	A					REVERSE IDLER SHAFT		2									
94		14283		B						WASHER - REVERSE IDLER		2									

EATON Engineering & Research Center

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Item No.	Part No.	Drawing Size	PL Rev.	Used in Item	Name	Qty.	Remarks
95	X-1-1008				NUT - HEX, SELF LOCKING, THIN (5/8-18)	2	SAE GRADE 2 NYLON INSERT
96	54589*	D	D		GEAR - MAINSHAFT 1ST	1	
97A	54785*	D	D		COUNTERSHAFT ASS'Y - FRONT BOX	2	
98	54593*	D	K	97A	1ST & REV. - COUNTERSHAFT	2	
99	55660*	C	G	97A	2ND GEAR - COUNTERSHAFT	2	
100	55787*	C	D	97A	3RD GEAR - COUNTERSHAFT	2	
101	54590*	D	D	97A	DRIVE & P.T.O GEAR - COUNTERSHAFT	2	
102	56338*	R	A		MACHINE DRAWING - FRONT BOX (2 SHTS)	1	CASTING 56332-R (2 SHTS)
103	81022	C			BEARING, BALL	2	
104	—				SNAP RING #974-R	2	EATON ENG. FASTENERS
105	X-8-809	B			CAPSCREW, HEX. HD. (1/2-13 X 1-1/2 LG)	4	SAE GRADE 5
106	X-3-801	B			LOCKWASHER - 1/2 SAE STD REGULAR	4	
107	15483	R	U		HOUSING, CLUTCH	1	SAE NO. 1
109	56832*	D			COVER - IDLER GEAR	1	SHEET 2
110	56833*	D			GEAR - IDLER	1	SHEET 2

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Item No.	Part No.	Drawing Size	Rev.	PL Rev.	Date	Used in Item	Name	Qty.	Remarks										
111	58719	B			3/21/85		BUSHING - CASTING BORE						SHEET 2						
112	---				3/21/85		BEARING - TAPERED ROOLER CUP 532X CONE 539	2					TIMKEN				SHEET 2		
113	56835*	C					SHAFT - IDLER GEAR	1									SHEET 2		
114	56836*	B					SHIM PACK - BEARING	1									SHEET 2		
115	---						FLANGE YOKE #6 1/2-2-329	2					SPICER				SHEET 2		
116	---						COMPANION FLANGE #6 1/2-1-741	2					SPICER				SHEET 2		
117	---						NUT - HEX (7/16-20)	24									SHEET 2		
118	---						LOCKWASHER (7/16 SAE STD REGULAR)	24									SHEET 2		
119	---						BOLT - HEX HD (7/16-20 x 1-1/4)	24					SAE GRADE 5				SHEET 2		
120	---						SEAL - OIL #34868 (3-1/2 x 4-3/8 x 7/16)	2					CHICAGO RAWHIDE				SHEET 2		
121	56837*	B					SPACER - BEARING COMPANION FLANGE	2									SHEET 2		
122	56838*	D					HOUSING - BEARING, OUTPUT REAR CUP 29620	1									SHEET 2		
123	---						BEARING - TAPERED ROLLER CONE 29675						TIMKEN				SHEET 2		
124	56839*	E					GEAR - OUTPUT DRIVE, REAR	1									SHEET 2		
125	56454*	R					MACHINING DRAWING - DROP CASE (2 SHTS)	1					CASTING DRAWING - 56840-R				(2 SHEETS)		
126	56841*	C					WHEEL - PICKUP	1									SHEET 2		

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Item No.	Part No.	Drawing Size	PL Rev.	Rev. Date	Used in Item	Name	Qty.	Remarks
127	—					MAGNETIC SENSOR & NUT #3030HTB	1	ELECTRO SHEET 2
128	56842*	D				CLUTCH - DOG, DRIVE	1	SHEET 2
129	56843*	D				CLUTCH - DOG, DRIVEN	1	SHEET 2
130	—					SNAP - RING	1	N5000-500 WALDES
131	—					BEARING - BALL#214-R	1	MRC SHEET 2
132	56844*	E				HOUSING - BEARING, OUTPUT FRONT	1	CASTING 56976-E
133	56845*	C				YOKE - DOG CLUTCH	1	SHEET 2
134	56846*	C				PISTON - DOG CLUTCH	1	SHEET 2
135	—					O'RING (1-7/8 x 2-1/4 x 3/16)	1	PARKER #2-328
136	—					SNAP - RING	1	N5000-231 WALDES
137	56847*	B				WASHER - DOG CLUTCH	1	SHEET 2
138	56848*	B				ROD - DOG CLUTCH	1	SHEET 2
139	—					SPRING - DOG CLUTCH #LHC-177P-3	1	LEE SPRING CO. SHEET 2
140A	57035*	E				CLUTCH ACTUATOR - AIR OPERATED	1	(SEE PL 57035) SHEET 2
141A	—					CLUTCH - ENGINE #127390X	1	DANA CORP. SHEET 2
142	56940*	D				OUTPUT SHAFT - FRONT	1	

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Item No.	Part No.	Drawing Size	Rev.	PL Rev.	Used in Item	Name	Qty.	Remarks
143						BUSHING AA-1332-10	1	OLITE SHEET 2
144						O'RING (5-5/8 x 6 x 3/16)	1	PARKER #2-358 SHEET 2
145						O'RING (5-1/4 x 5-1/2 x 1/8)	1	PARKER #2-252 SHEET 2
146	56963*	C				GASKET - BEARING HOUSING, FRONT	1	
147	56944*	B				COVER - DROP CASE	1	SHEET 3
148	56945*	B				GASKET - COVER, DROP CASE	1	SHEET 3
149						BOLT - HEX HD (5/16-18 x 3/4 LG)	6	SHEET 3
150	56968*	C				GASKET - AUX SHIFT TO DROP CASE	1	
151	56918*	B				NUT - JAM	1	
152	58717	B		3/21/85		SPACER - RING TIMKEN INNER	1	SHEET 2
153						HEX. HEAD SCREW - 3/8-16 x 4" LG	9	
154						HEX. HEAD SCREW - 3/8-16 x 1" LG	2	
155	58718	B		3/21/85		SPACER - RING TIMKEN OUTER	1	SHEET 2
						REF DWGS		
	56403	C				INTERFERENCE STUDY - SHIFT YOKE		
	56651	C				SCHEMATIC - AIR SYSTEM MODIFICATION		

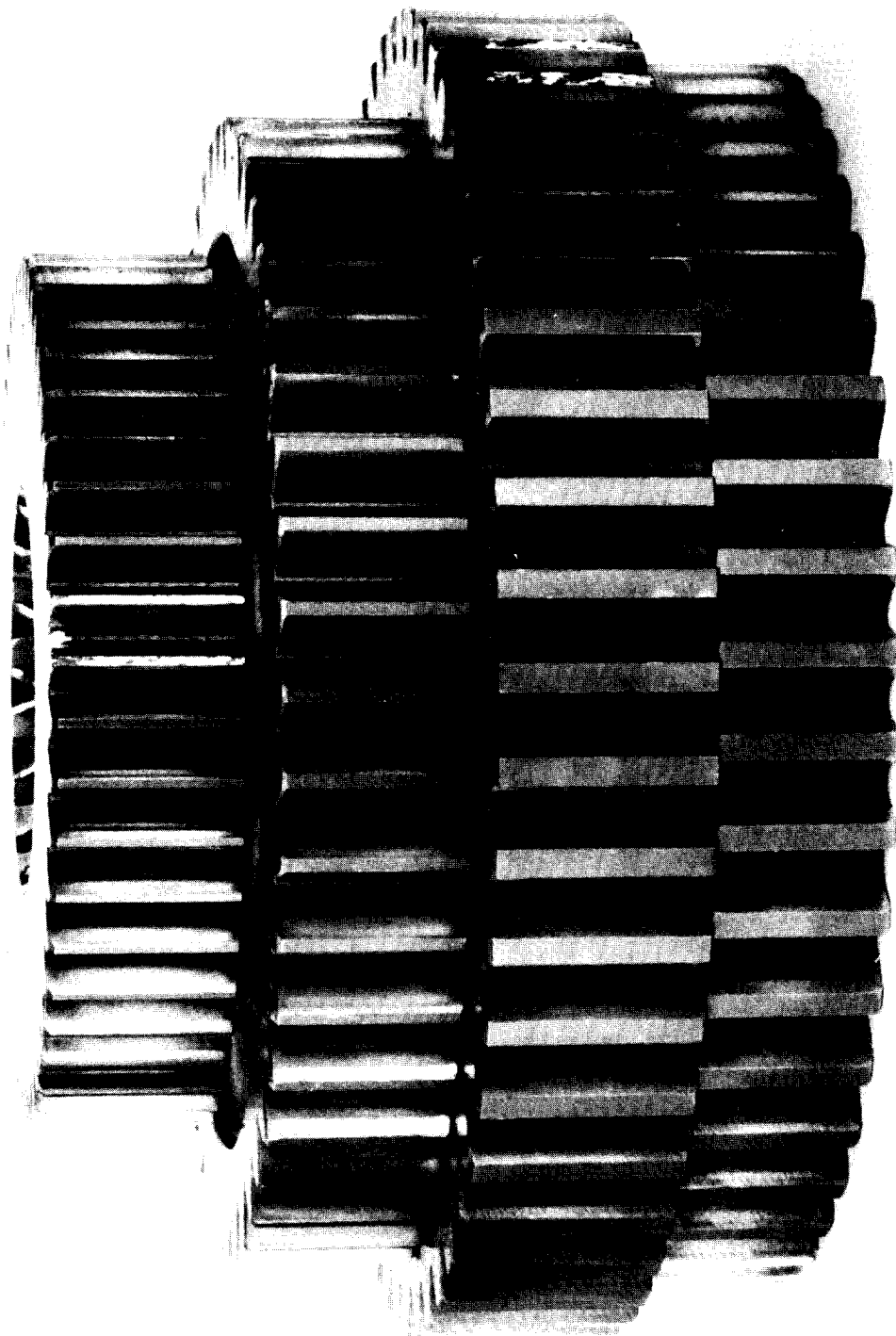


Figure 4-15. Front Mainshaft Gears

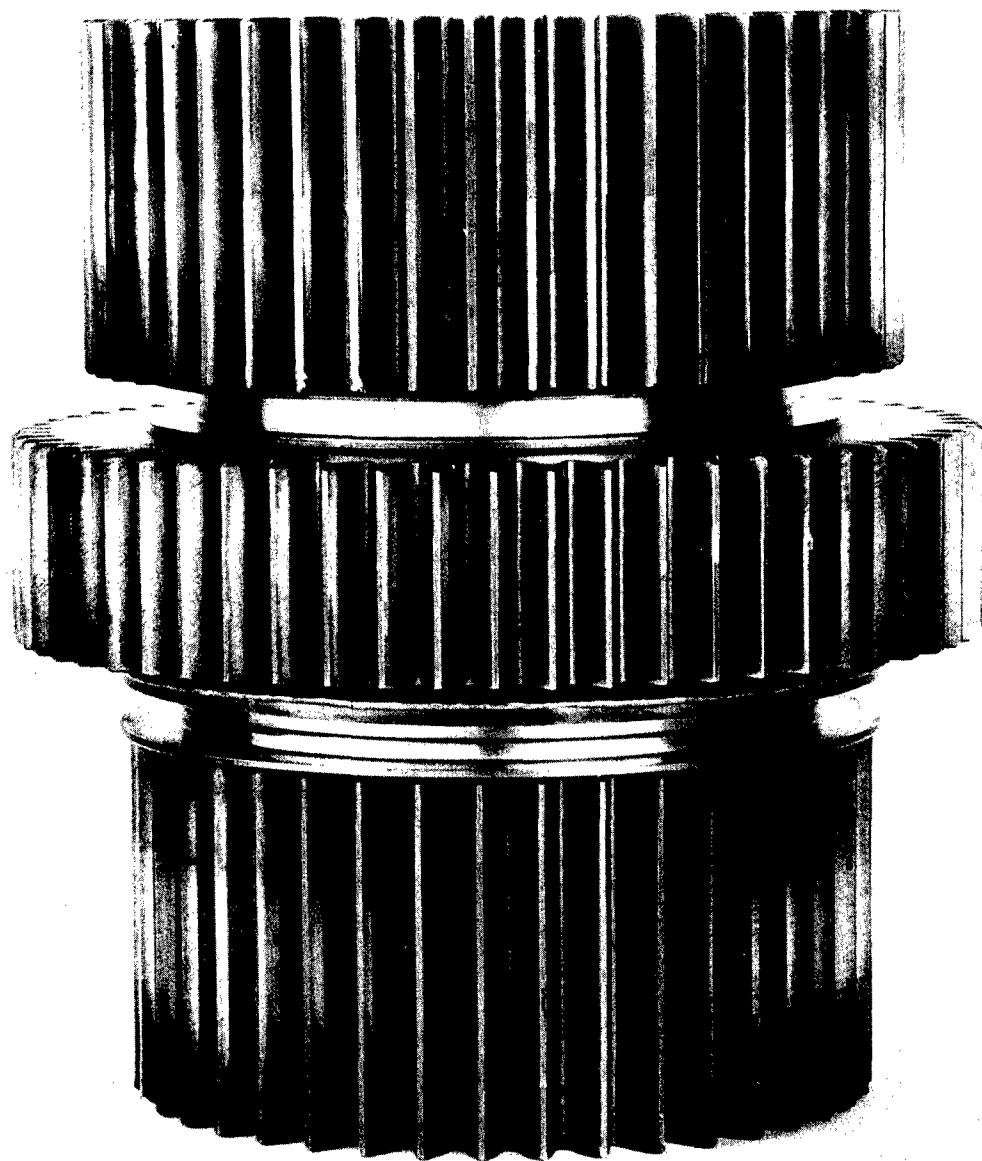


Figure 4-16. Auxiliary Mainshaft Gears

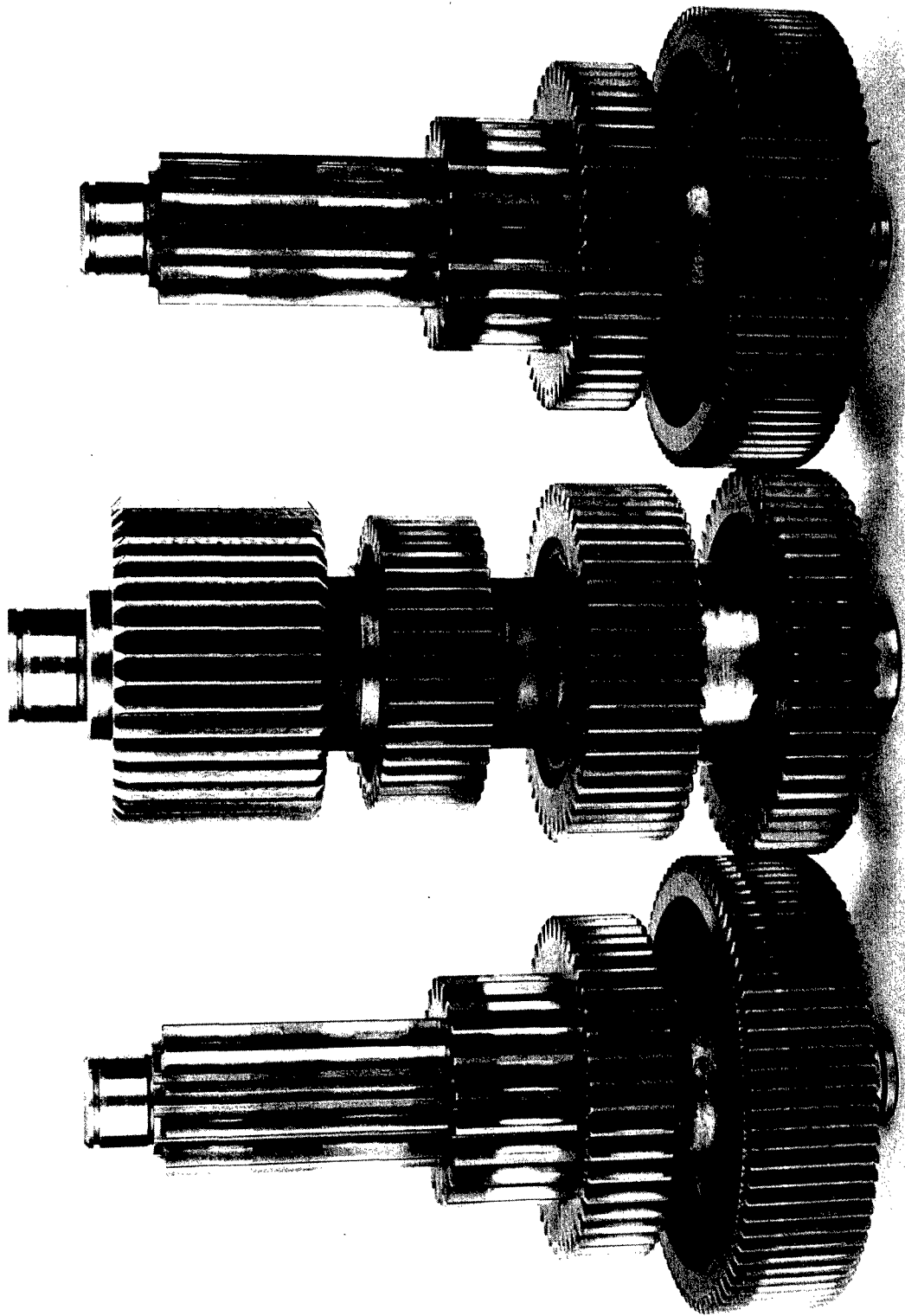


Figure 4-17. Countershaft Gears

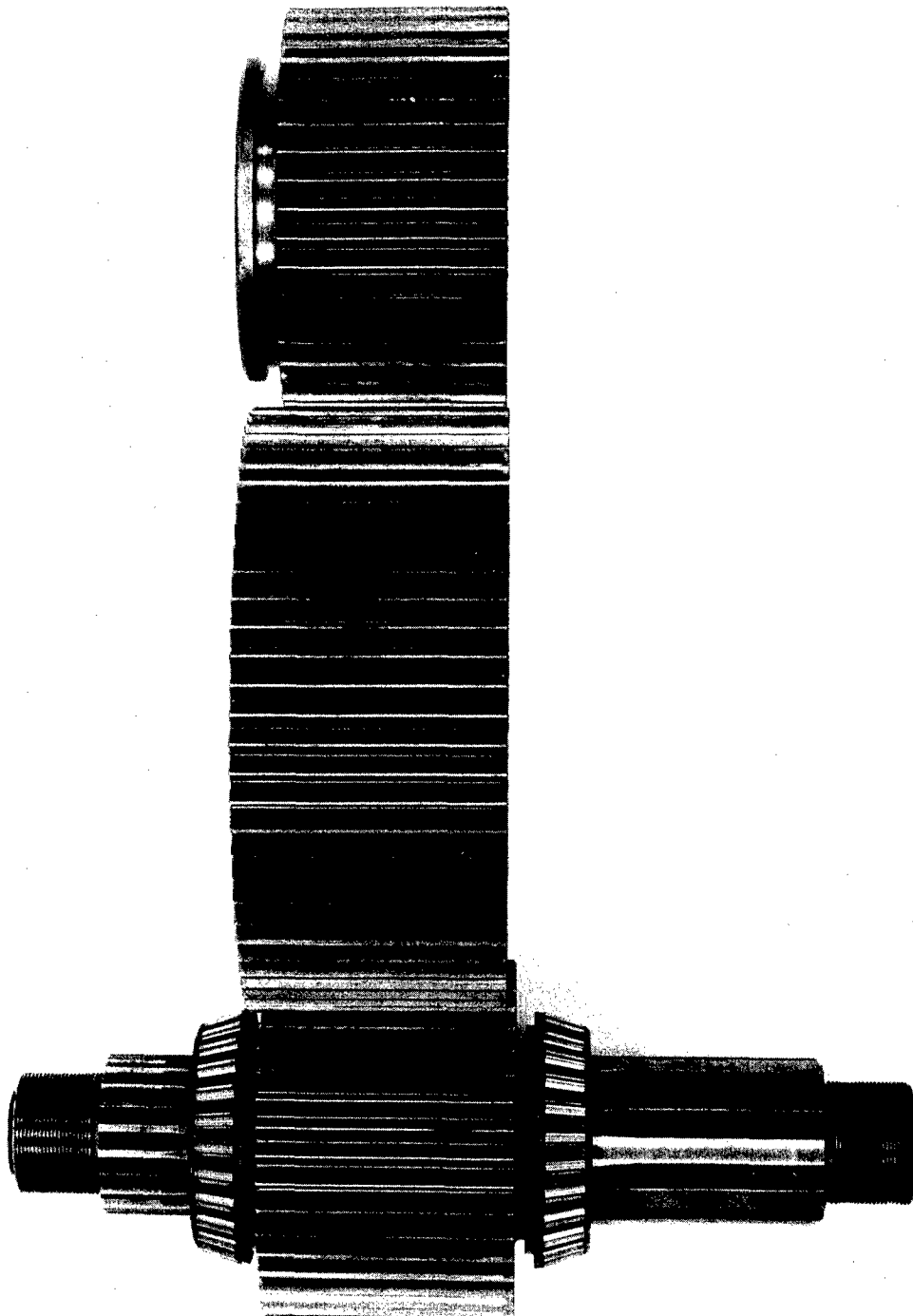


Figure 4-18. Drop Box Gears

The drop box gears were shotpeened before testing in order to impart a residual compressive stress in the roots of the teeth. This operation historically extends gear life in bending and was deemed necessary because of the duty cycle required (gear set transfers all loads from transmission to axles). The gears were submitted to Eaton's metallurgical department for conformation of residual compressive stress. A Fastress machine was used to measure the stresses before and after testing. It was determined that the gears exhibit high compressive stresses at the surface (see Appendices D and E).

4.6.3.2. Bearing inspection. All bearings were cleaned and found to be in good condition with two exceptions.

A needle thrust bearing had failed during the test due to the transmission's mainshaft being out of adjustment, causing a preload on the bearing. Installation of a new bearing and proper mainshaft adjustment will correct the problem.

The other problem bearing was a ball bearing used to support the drop box's front driveshaft. Although no failure occurred during the Aberdeen test, the bearing failed twice during Eaton's testing. Both times the cage that holds and positions the balls failed. The cause of the failure was attributed to excessive thrust from the driveline. A spherical roller bearing was chosen as a replacement. The bearing has 10 times the calculated life of the original ball bearing, and installation requires only a minor housing modification.

4.6.3.3. Dog clutches. The dog clutches were measured for wear. The type and amount of wear was found to be typical of Eaton transmissions with dog clutches. The clutches could be reused but were replaced since the parts are standard stock items and readily available. A description of the type and amount of wear follows.

- The 3-4 dog clutch teeth were worn on drive and coast side of both ends. The type of wear was rounding of the ends of the teeth, and the amount was .060 inches (see Figure 4-19E).
- The 1-2 dog clutch teeth were worn on the drive side of the first gear end. The type of wear was a rounding of the ends of the teeth, and the amount of wear was .050 inches (see Figure 4-19G).
- The teeth on the reverse dog clutch exhibited no wear (see Figure 4-19D).
- The teeth on the low dog clutch were rounded .03 inches on both drive and coast side (see Figure 4-19C).
- The teeth on the intermediate dog clutch were rounded .04 inches on both drive and coast side (see Figure 4-19B).
- The overdrive dog clutch teeth were rounded to .04 inches, and the wear extends along the tooth .10 inch on both drive and coast sides (see Figure 4-19A).
- The direct dog clutch teeth are rounded by .04 inches on both drive and coast side. Wear extends .125 inches along tooth (see Figure 4-19F).

4.6.3.4 . Front drive clutch. Inspection of the curvic coupling revealed no wear or distress of any kind. This hardware is currently used in Eaton tandem drive axles for heavy-duty trucks and worked well in this application.

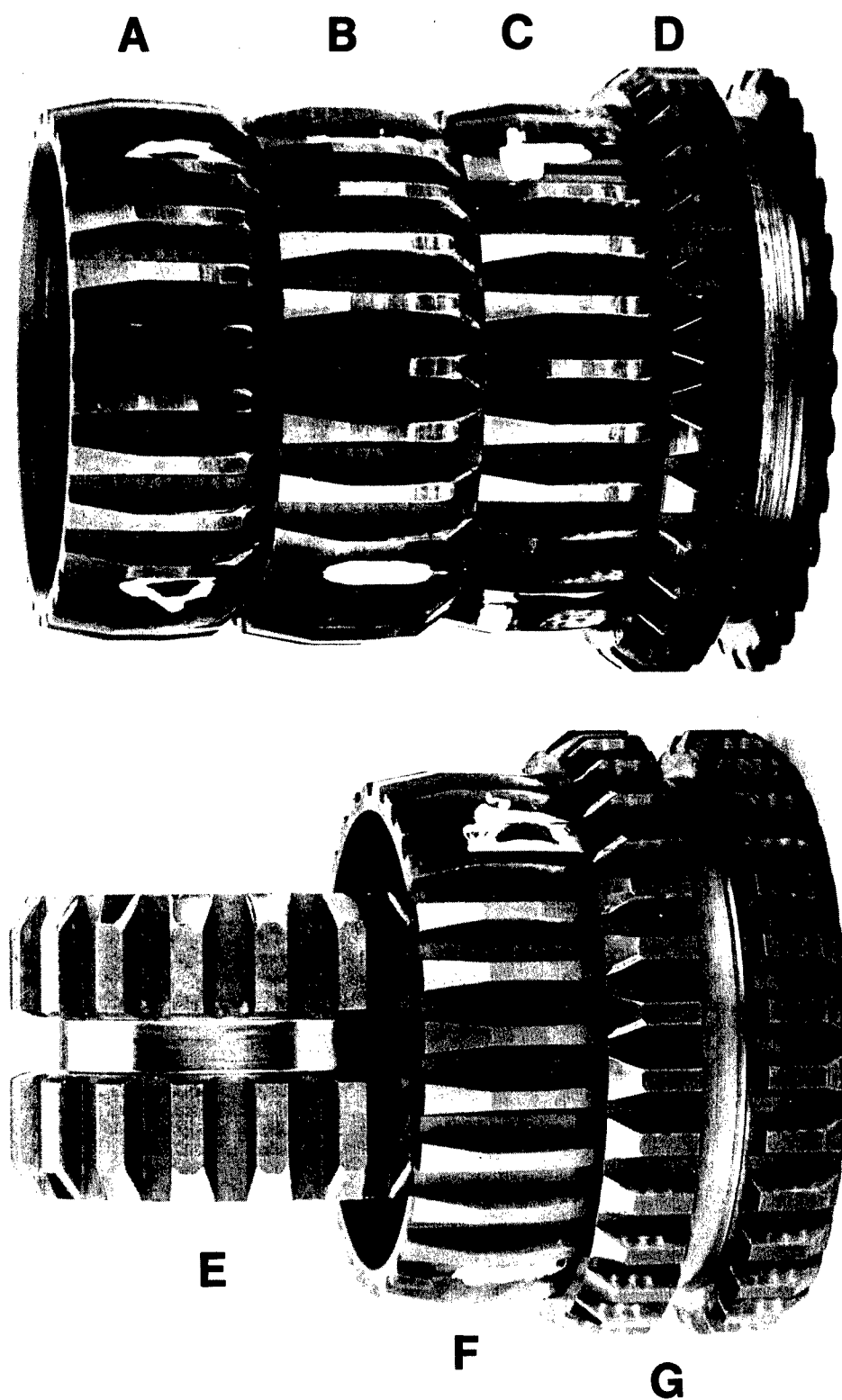


Figure 4-19. Dog Clutches

4.6.3.5. Shift forks. The transmission's shift forks were magnafluxed and checked for cracks. All forks were found to be crack-free except the fork that is used to engage front wheel drive. The cracks were on the left finger and are of the heat check variety (see Figure 4-20.). The heating and associated cracks were probably the result of the front drive bearing's failure because lack of bearing support would allow extreme misalignment and thrust loads on the fork.

The forks were also measured for pad wear. A review of Table 4-7 shows high pad wear (note .050 maximum wear allowed) on the 3-4 fork, as well as the front wheel drive fork (see Figures 4-20 and 4-21). The remaining forks exhibit minimal wear on the heat treated pads (see Figures 4-22 through 4-25). Replacement of the front wheel drive fork because of excessive pad wear and heat cracks and the 3-4 fork because of pad wear is deemed necessary.

4.6.4. Parking Brake Description. A parking brake is optional on the TSO-11616 automated mechanical transmission. The assembly is supplied by Auto Specialties Manufacturing Company (AUSCO) of St. Joseph, Michigan. It is mounted high on the rear face of the transmission on an extension of the normal output shaft. In this location, the brake is above the driveshafts, between the frame rails.

The internal components of the brake (actuating discs, friction materials, etc.) are standard 11 - by 8 - inch disc components made by AUSCO. The brake design incorporates a degree of self-actuation which allows more braking capacity than a drum brake of comparable size. Self-actuation is provided by actuating discs which are separated by balls on inclined seats (ramps). As the actuating discs are applied (rotated in opposite directions), the balls roll up the ramps, separating the discs to absorb running clearance. This allows the actuating disc to contact the friction discs which are attached to the output shaft extension. Once in contact, any load on the friction discs is applied through the ball ramps back to the actuating disc to provide self-actuation. In addition, the design provides ease of adjustment and the ability for both mechanical or automatic actuation in the same package.

The brake has sufficient capacity to hold a 35,000-pound vehicle on a 60% grade with 969 pounds of pull on the actuating rod. This is accomplished with four disc plates, each with friction surfaces measuring 11 inches outer diameter and 8 inches inner diameter.

4.6.5. Parking Brake Inspection. The Auto Specialties parking brake was disassembled and checked for wear. An AUSCO representative was available to discuss the condition of the brake.

The overall condition of the brake was found to be good with the exception of the friction plate splines and their mating adapter hub. The splines on the plates and hub exhibited extreme material deformation on both the drive and coast side of the teeth. This was believed to be caused by the high speeds and torsional loads present. The AUSCO representative stated that the combination of loads and speeds is not typical for this model brake. He recommended change in material from 1017 steel to 1030 steel and induction hardening of the plate spline along with carbonitriding the teeth on the adapter hub.

Another area of concern was some spalling of the friction material. The AUSCO representative stated that 2% of the discs may have localized spalling due to a "weak interface structure." This would not, however, affect performance. See Appendix F for brake inspection report by AUSCO.

Table 4-7. Fork Wear*

Fork	Left Pad			Right Pad		
	1	2	3**	1	2	3**
1-2	.000	.002	.005	.002	.002	.005
3-4	.034	.045	.045	.020	.033	.038
Reverse	.000	.000	.002	.000	.000	.002
Low	.013	.016	.016	.008	.009	.009
Int.-O.D.	.007	.008	.009	.010	.013	.016
Direct	.011	--	.019	.013	.015	.018
Front Wheel						
Drive	--	--	.020	--	--	.012

*Wear values are an average of the measurements taken.

** Measurement 1 taken 9/19/85
 Measurement 2 taken 2/19/86
 Measurement 3 taken 6/36/86



Front

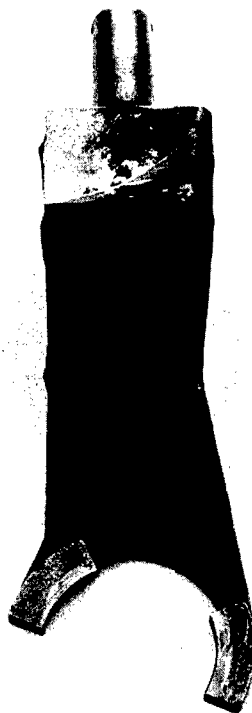


Rear

Figure 4-20. Front Wheel Drive Fork

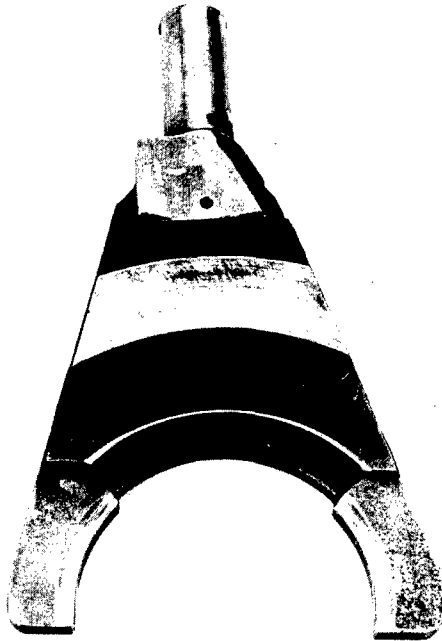


Front

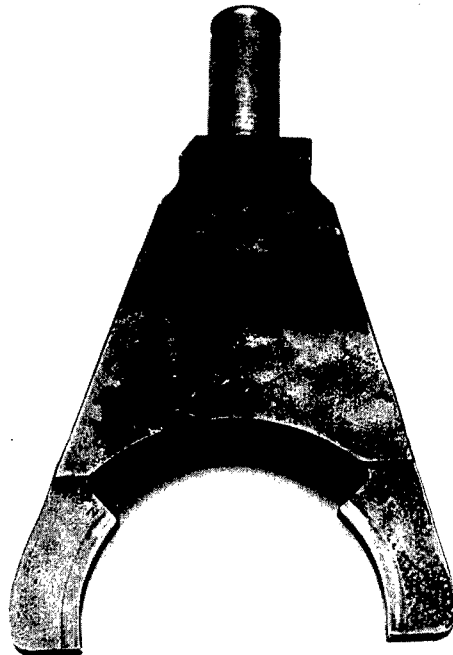


Rear

Figure 4-21. 3-4 Fork

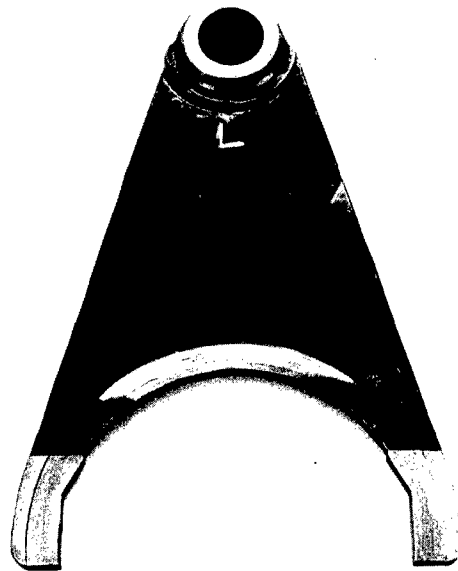


Front

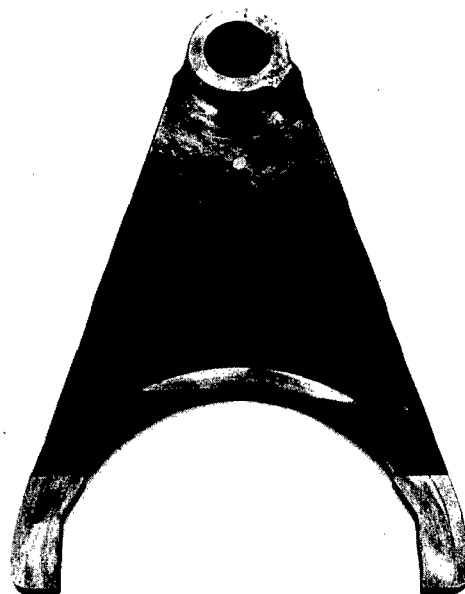


Rear

Figure 4-22. 1-2 Fork

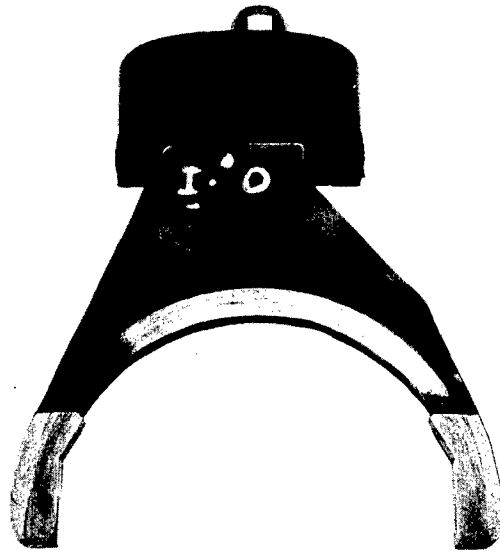


Front

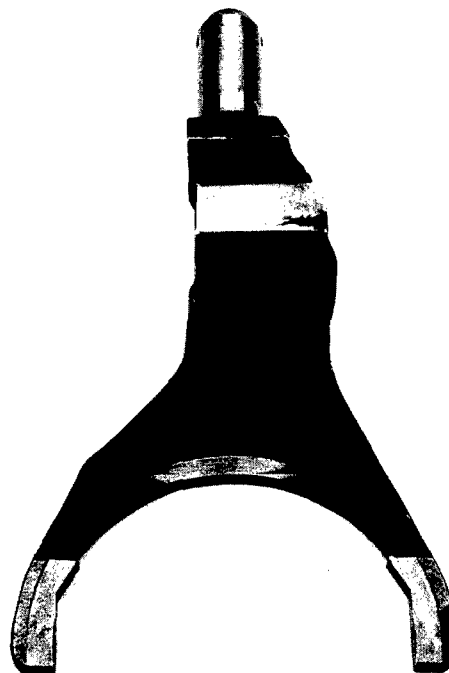


Rear

Figure 4-23. Low Fork

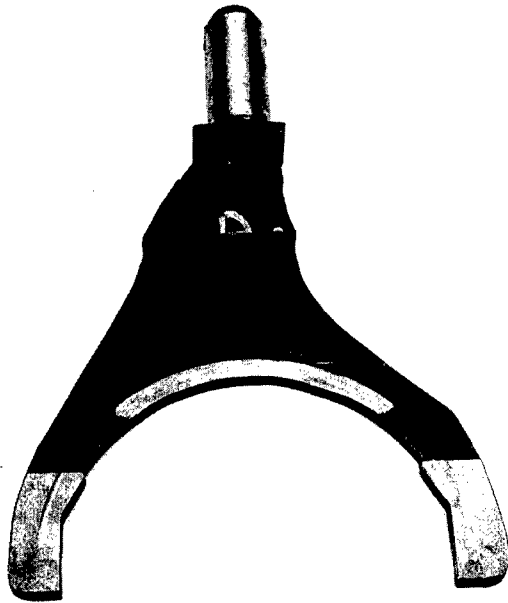


Front

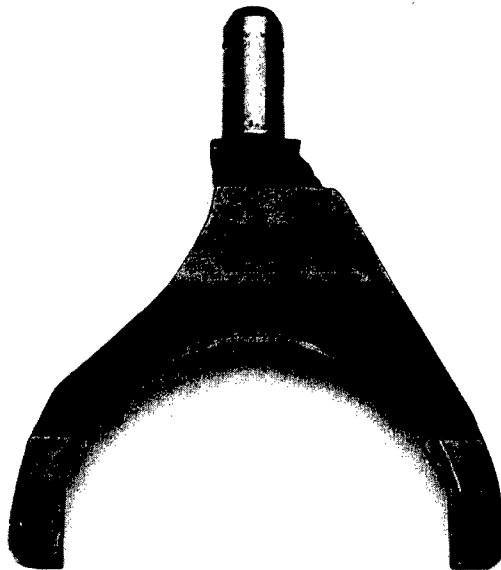


Rear

Figure 4-24. Intermediate-Overdrive Fork



Front



Rear

Figure 4-25. Direct Fork

4.6.6. Main Box Air Shifter Description. The main box shifter is used to select the proper main section gear ratio. In effect, it replaces the driver's muscle. Mounted on top of the shifter assembly is an air valve manifold assembly which operates the shifter and other devices. A longitudinal cross section through the shifter and manifold is shown as Figure 4-26. A transverse cross section of the shifter is shown in Figure 4-27, which illustrates the piston and shift yoke arrangement.

The air shifter assembly uses three shift pistons to engage the five main box gear ratios. Two pistons are double acting and one is single acting. A set of interlock pins between the different piston shafts prevents simultaneous engagements of more than one gear. This is an important requirement in any mechanical gear box shift mechanism.

The shift pistons are returned to the neutral position by air-operated neutral pistons. The air supply to both the neutral pistons and the shift pistons are through solenoid-operated three-way valves in valve manifold. In the event of a loss of power to the shifter while underway, the shifter would remain in the selected gear. If springs were used instead of neutral air pistons, the shifter would be forced neutral in the loss of electrical power.

Another feature of the air shifter is that it uses a cross-shaft contacting each air piston to sense when the main box is in neutral. This shaft activates a switch to provide the feedback to the electronic controller. Sensing neutral is an important action in the shift sequencing.

The shift yokes are allowed limited rotation in the shift piston at their point of attachment. This allows the shift yoke to accommodate some slight misalignment between the transmission mainshaft and the shifter housing.

4.6.7. Main Box Air Shifter Inspection. The shifter was disassembled and checked for wear of the mechanical hardware and deterioration of electrical components. The shifter did not require any rework and, therefore, was just reassembled. It was cycled on the bench to check for function and to detect any air leaks before being attached to the transmission.

4.6.8. Auxiliary Box Air Shifter Description. The construction, actuation and operation requirements of the auxiliary box air shifter are basically the same as the requirements of the front box air shifter.

It uses three shift piston shafter for the four gear ratios, plus neutral. The piston shafts are returned to neutral by air pressure. Of the three shift pistons, one is used in two directions for intermediate and overdrive gears, while the pistons for low and direct stroke in one direction only. The air shifter for the auxiliary has been designed specifically for this application.

The shafts have a mechanical interlock to assure that multiple gear selections cannot be made, and a switch is activated when the auxiliary section is in neutral.

The four-solenoid operated, three-way insert air valves required to operate the auxiliary shifter are integral to the assembly. This optimizes the air valve performance.

Testing has indicated the importance of both sufficient force as well as flow capacity to shift fast for off-road mobility.

4.6.9. Auxiliary Box Air Shifter Inspection. The mechanical components of the shifter were found to be in good condition. Following disassembly all of the O-ring seals were functioning properly. The solenoid-operated valves were function tested. The shifter was reassembled and checked for air leaks and proper operation.

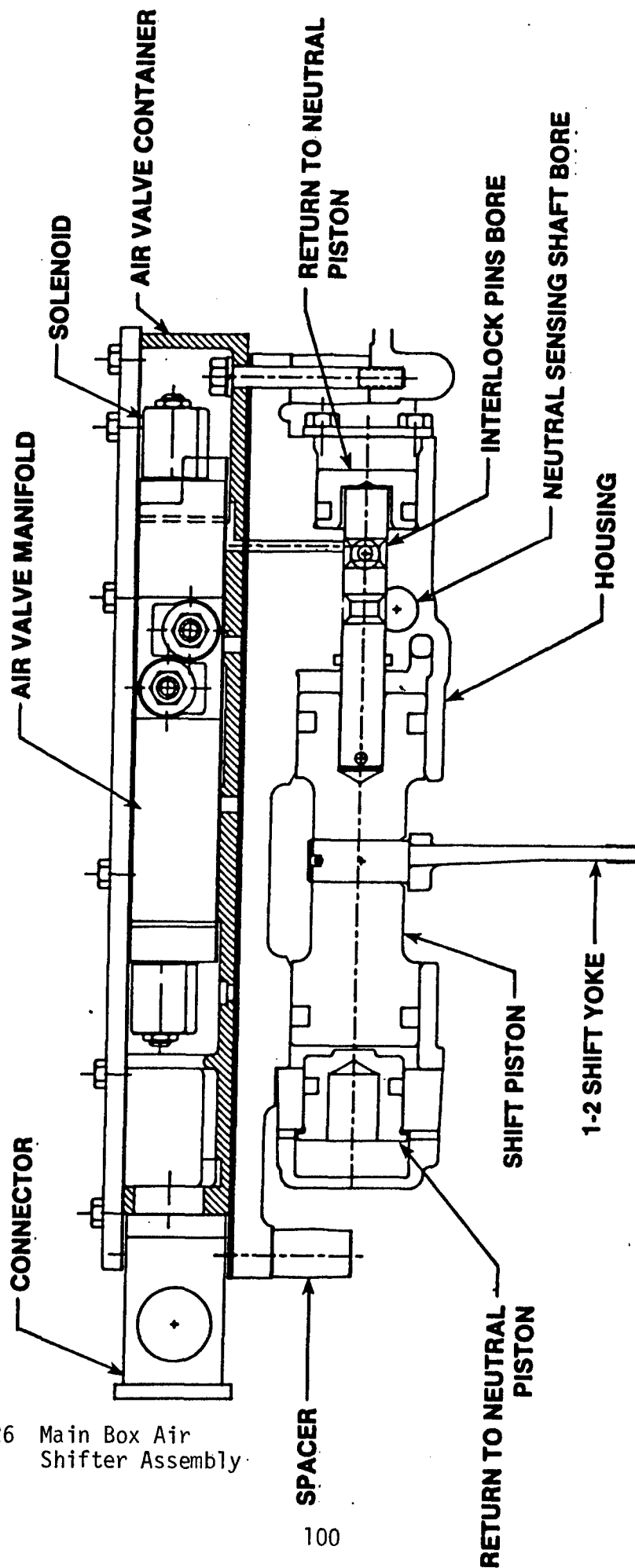


Figure 4-26 Main Box Air Shifter Assembly

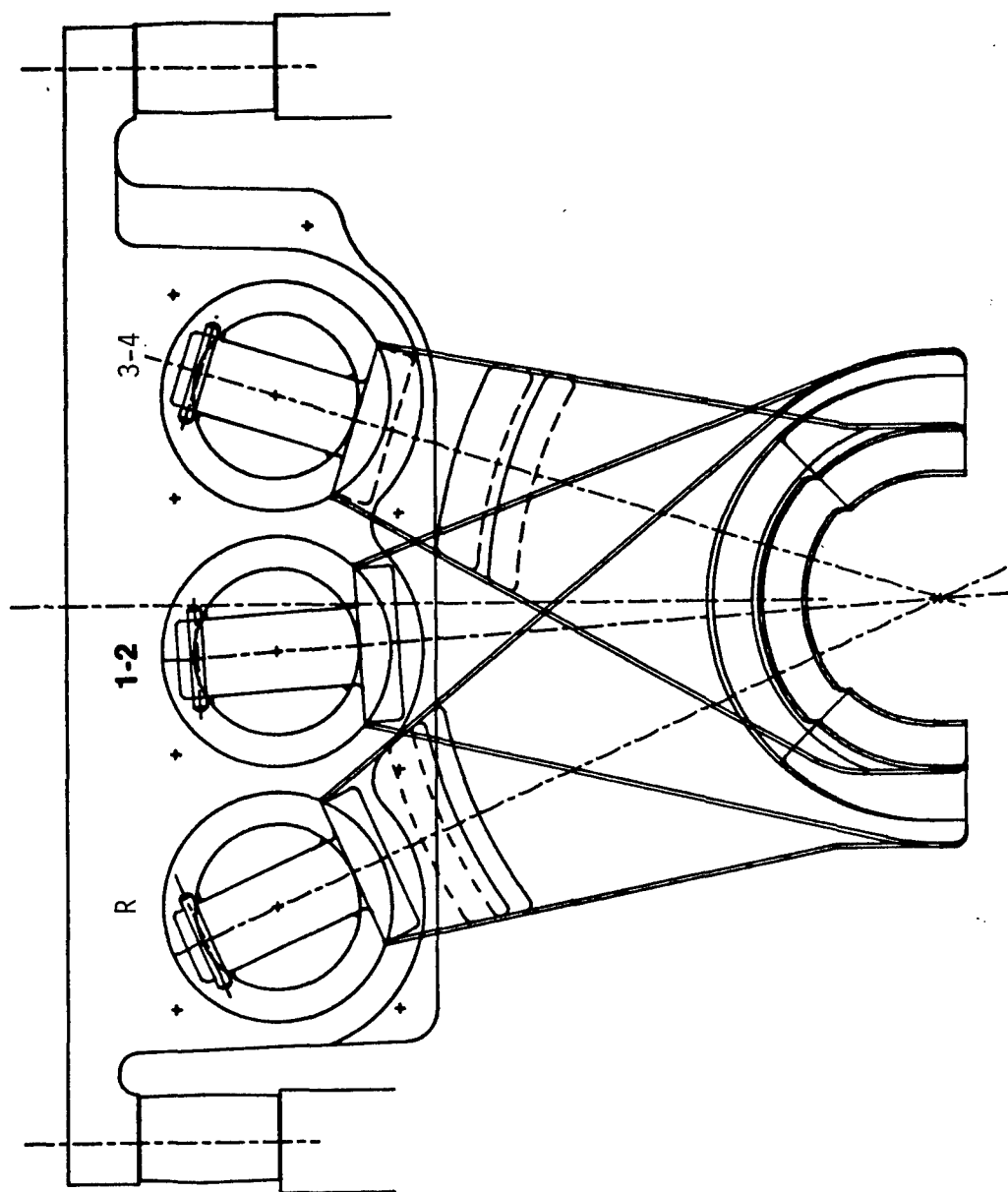


Figure 4-27 Main Box Air Shifter Fork Arrangements

4.6.10. Input Brake Description. The input brake is used to slow down the transmission input gearing and the clutch-driven discs during shift synchronization. When the input is rotating faster than the required speed for synchronous dog clutch insertion, the brake is applied momentarily to slow it down.

The brake assembly being used is normally mounted on the six-bolt PTO pad on the right side of the transmission (see Figure 4-28). Hardware is available to adapt the brake assembly to the bottom eight-bolt PTO pad.

The input brake is a multiple-plate design actuated by air pressure. The gear in the brake assembly meshes with the headset countershaft gear and thereby with the input section of the transmission. When air is applied, the input gearing is grounded to the transmission case, causing the brake action.

The normal transmission oil flows in and around the brake assembly.

The air piston force and number of active surfaces are sized to give a deacceleration rate of 3,000 to 4,000 RPM/second measured at the input shaft.

In order to achieve the very fast on-and-off characteristics required for fast shifting in off-road conditions, a pilot-actuated valve has been mounted directly to the brake assembly. The solenoid valve in the air valve manifold has only to provide the pilot signal to activate the integral valve. This has reduced the actuation time by 63% in reducing the response time from 0.08 seconds to 0.03 seconds.

The brake is activated by the logic when the clutch is disengaged and the splitter section is in neutral. The brake turn-off time is determined by means of a lead circuit which senses the synchronization error and the rate of change of input speed in order to have the brake fully off before the jaw clutch in the auxiliary section makes engagement. If the brake is not deactivated soon enough, it creates a retarding force which is significant and noticeable in the lower gears.

4.6.11. Input brake Inspection. The plates were checked for wear and or any distress due to high temperatures.

The friction plates' material exhibited signs of use when compared to new plates, but were not worn enough to require replacement. The steel separator plates were like new and did not exhibit any signs of being exposed to high temperatures. No problems were found with the spline teeth on any plates. Both sets of plates can be used for reassembly.

4.7. Rebuild for Modern Technology Demonstration Truck

4.7.1. Mechanical System. The unit was rebuilt using most of the original test parts. All parts that were reused were inspected, deemed to be sound, and exhibited no more than minor use.

The parts that were replaced could be placed in three categories: routine (a good practice), upgrades, and refinements.

4.7.1.1. New drop box gearing. The replacement of the drop box gearing could be considered a refinement since the only change from the original gearing was to use gears with modified tooth profiles in order to apply the latest noise control technology.

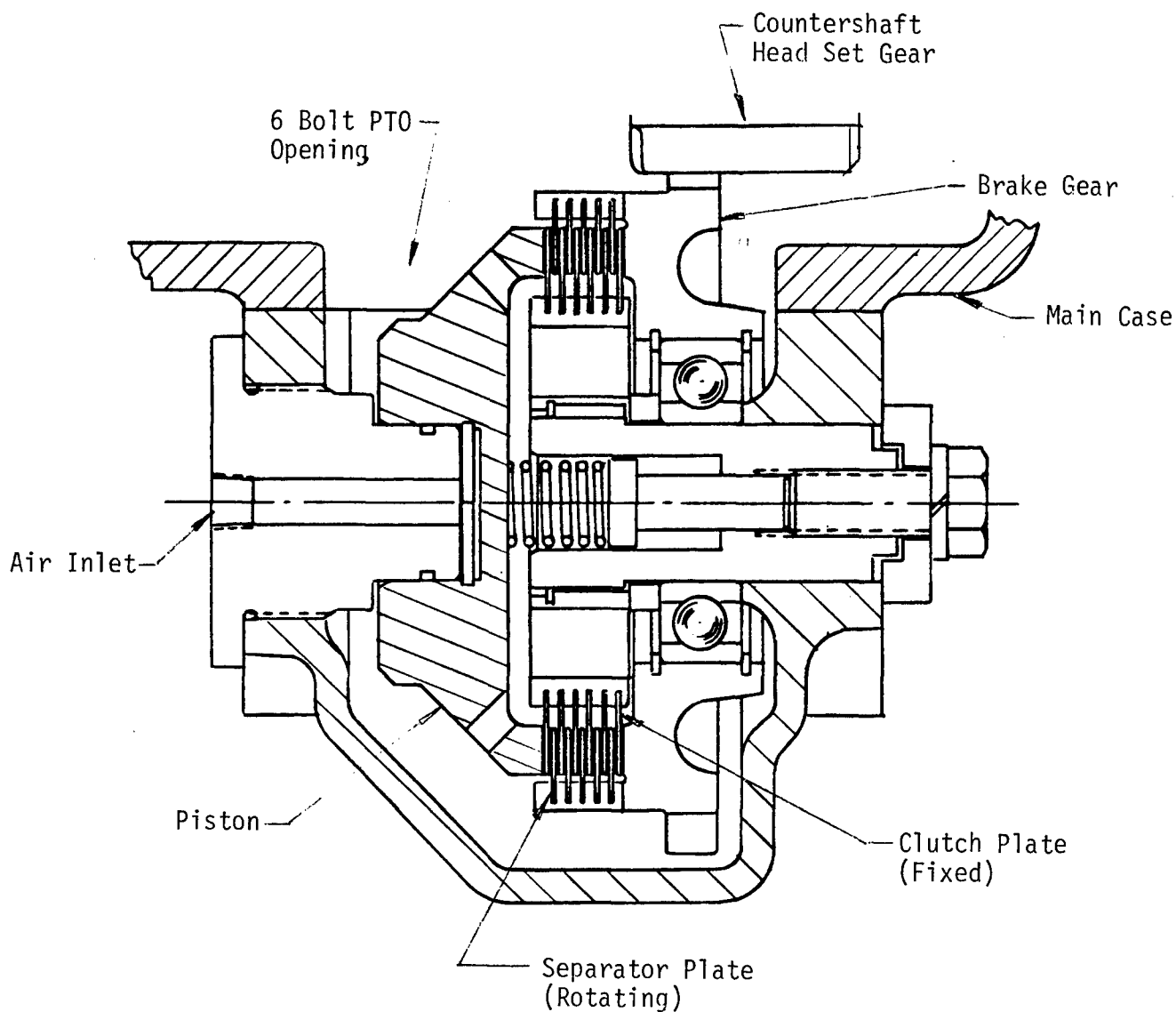


Figure 4-28 External Input Brake Assembly

4.7.1.2. Production transmission housing. Another refinement was to replace the main transmission housing with the production housing. This new housing also allows the upshift brake to be mounted internally on the bottom. This eliminates the external side-mounted brake which interfered with the truck's frame rail and was extremely time consuming to install.

4.7.1.3. Mainshaft locking spline. A step lock spline was incorporated between the direct dog clutch and the direct mainshaft gear. This spline is required to aid in elimination of the 3rd gear kick-out problem that occurred while climbing the 29% grade on Churchville "B." The splines are shown in Figure 4-29.

4.7.1.4. Front drive bearing. The ball bearing that supports the drop box's front drive shaft needed to be upgraded. It failed twice during Eaton's testing but never during the Aberdeen test. A spherical roller bearing was the chosen upgrade. The new bearing has 10 times the calculated life of the old bearing and should provide more than adequate performance.

4.7.1.5. Additional components. A number of new components were added to meet the requirements of a single point for actuator exhaust, supply air, and oil cooler lines. This requirement was part of the stand-alone power pack design. A single air exhaust manifold was fabricated and installed (see Figure 4-30).

4.7.1.6. Dog clutches. Parts were replaced as a matter of good practice since spare hardware was available.

4.7.2. Improved Acceleration Times. Zero to thirty MPH acceleration data was taken on both the microprocessor version of military AMT controller as well as the hybrid version. This data is also compared to test data for an Allison equipped vehicle (see Table 4-8).

Two sets of data are shown for the microprocessor version due to two different shift algorithms being used. Eaton Micro 1 did not allow as many multiple upshifts as did the Eaton Micro 2 tests. It should be noted that the Eaton Hybrid controller did not allow any multiple shifts.

The Micro 1 version has been selected as the overall best performance algorithm despite the faster acceleration times seen in the Micro 2 version.

The Eaton microprocessor version can be seen to accelerate from zero to thirty at least 1.7 seconds faster than the Eaton Hybrid version. If Micro 2 data is used, then microprocessor version would be 2.4 seconds faster.

4.7.3. Electronic Control System. The electronic control system (ECU) for the Automated Mechanical Transmission automatically performs all of the functions to operate the main clutch and shift the TSO-11616 transmission. In the previous ECU, the control functions were implemented using a combination of analog and digital logic circuits to process information from the input sensors to control the output actuators. This "hybrid" ECU has been replaced by an Mk1 ECU which employs two 16-bit microprocessors to perform the same functions as the previous system with several significant performance enhancements. In addition to providing these performance enhancements, the microprocessor-based Mk1 ECU uses fewer electronic components with more ruggedized construction in a new immersible package with military connectors.

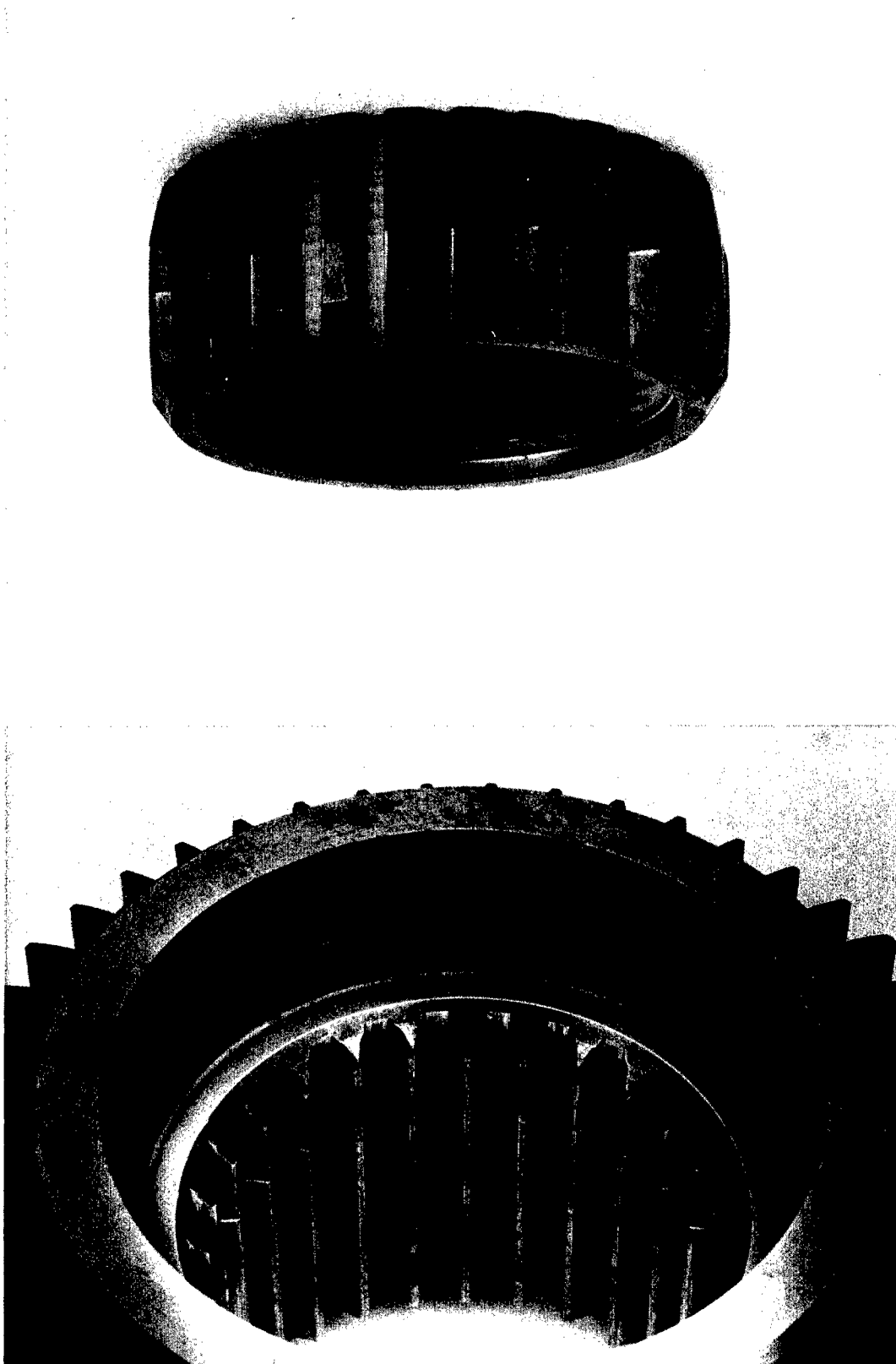


Figure 4-29. Locking Spline

Figure 4-30 Air Exhaust Manifold

Table 4-8. Acceleration Data

Transmission	Vehicle Weight	0-30 MPH Times
Allison	42,600 lbs.	25.0 sec.
Eaton Hybrid	32,639 lbs.	23.0 sec.
Eaton Micro 1	32,600 lbs.	21.3 sec.
Eaton Micro 2	32,600 lbs.	20.6 sec.

The new enhanced features provided with this system include:

- improved throttle control,
- throttle system fault tolerance,
- the ability to perform skip upshifts in on-highway operation,
- enhanced power downshifts,
- automatic control of the all-wheel drive,
- elimination of one reverse position on the gear selector
- speed sensor fault tolerance,
- an interface to an electronically controlled engine, and
- available options not implemented, including cruise control and road speed governing.

4.7.3.1. Optional improved throttle control. The original transmission system used a pneumatic control system to override the fuel pump control lever position to provide more or less fuel than that which was demanded by the driver's foot pedal position. Although functional, this pneumatic system provided less than desirable control resolution which limited shift quality, and there was some small, but noticeable, reaction force on the pedal when the override was in effect.

In new systems, the mechanical linkage between the foot pedal and the fuel pump control lever along with the previous pneumatic controls have been replaced by a "drive-by-wire" fuel control system. In this system, the foot pedal is used only to operate a potentiometer which is electrically connected to the ECU and provides the ECU with a signal indicating how far the driver has depressed the foot pedal. Connected to the fuel pump control lever is a small D.C. gear motor or actuator which is controlled by the ECU, and a potentiometer which is electrically connected to the ECU and provides the ECU with a signal indicating how far the actuator has actually moved the fuel pump control lever. The foot pedal sensor, actuator, and ECU make up a closed-loop position control system.

In operation, this system moves the fuel pump control lever in response to the driver's foot pedal position just as the mechanical linkage did. During a shift, when the transmission control system needs to provide more or less fuel than the driver is demanding, the system controls the movement of the actuator accordingly. When the shift is complete, the system reverts back to moving the fuel pump control lever in response to the driver's foot pedal position. The resolution in control using this system provides a significant improvement over the previous pneumatic system resulting in improved shift quality. In addition, there is no reaction force at the foot pedal during the override conditions.

The linkage between the actuator and the fuel pump control lever contains an overtravel element that protects the gear motor in abusive situations. Redundant return springs mounted from a fixed point to the fuel pump control lever ensure that the fuel pump control lever will return to the idle position in the unlikely event of a loss of electrical

power. The foot pedal sensor includes redundant return springs to provide a firm, but not strenuous, pedal force.

For the Modern Technology Demonstration truck, this optional throttle control was not used, as a direct electronic link as described in section 4.7.3.8. was used.

4.7.3.2. Throttle fault tolerance. The inclusion of the "drive-by-wire" fuel control results in a system where the engine fueling, clutch torque and transmission operation is under the control of an ECU. To prevent the occurrence of a hazardous situation in the event of a malfunction in any part of the electronic controls, a significant effort was made to make the system failsafe and fault tolerant.

A safety switch is included in the fuel pump control actuator which provides a signal which is electrically independent of the feedback potentiometer that indicates that the fuel pump control lever is in the idle position. If the system is commanding the fuel pump to be at the idle position, and either the switch or the feedback pot imply that the idle position has not been reached, then the system de-energizes the fuel shut-off solenoid, which turns off fuel to the engine.

Two safety switches are included in the foot pedal sensor. The throttle set (THS) switch indicates that the driver has his foot on the pedal and a second switch indicates that the driver has depressed the pedal all the way through a "ride-through detent" (RTD) and is requesting full fuel. The state of these two switches is continuously monitored and compared with the information received from the pedal position sensor. If the information does not agree, a failsafe condition of bringing the fuel pump control lever to its idle position is enforced.

4.7.3.3. Skip upshifts. The TSO-11616 transmission has 16 forward gear ratios. The new system retains the ability to select different starting gears by selecting one of three drive positions on the gear selector. D1 (Drive 1) selects 1st gear as the starting gear, D2 (Drive 2) selects 3rd, and D (Drive) selects 5th. The D (Drive) position is used in the less demanding driving situations. In these situations, the small gear steps available in this 16-speed transmission should be shifted by one or two gears in these cases. This control enhancement eliminates much of the unrequired shifting in the lower gears, which results in a smoother and faster acceleration of the vehicle. If the load on the vehicle increases, the system will upshift by one or two gears automatically as the situation requires.

4.7.3.4. Power downshifts. In off-road driving, one often encounters a situation in which a steep grade is encountered and the transmission is required to downshift by several gears to pull the grade. In the previous system, the transmission would downshift sequentially two gears at a time as the vehicle speed decreased on the grade. As a result, because of the number of shifts made and the fact that torque is interrupted during a shift, the vehicle speed would often decrease below that speed at which the vehicle was power limited.

The utilization of microprocessor technology allows more intelligent shift decision strategies to be implemented. The enhanced power downshift strategies implemented in this system use vehicle deceleration to anticipate the gear required to pull the grade. The new system automatically makes fewer shifts of larger steps as required, thereby decreasing the amount of time spent shifting, resulting in higher average vehicle speeds in these situations than was capable with the previous system.

4.7.3.5. All-wheel drive control. In operation, it was found that many inexperienced drivers did not know under what circumstances they needed to engage the all-wheel drive until they were well into the conditions where they needed it. When it became apparent to the drivers that they needed the all-wheel drive engaged, they would engage it under high torque conditions which, in doing so, would deliver a near damaging shock to the driveline. Virtually all drivers knew to select one of the off-road drive ranges, either D2 or D1, well in advance of its need.

To minimize the situations where the all-wheel drive is engaged under high torque conditions, the new system automatically engages the all-wheel drive whenever one of the off-road drive ranges is selected. This "automatic" feature makes the vehicle easier to drive since the all-wheel drive is engaged before you need it and reduces the potential for damaging the driveline.

4.7.3.6. Single reverse selection. The previous system had two reverse gear selector positions to select one of two reverse gear ratios. The new system automatically selects the reverse gear ratio based upon the last used drive position. The least reduction reverse gear is selected if the last drive position was D (Drive) which is used in on-highway driving. The greatest reduction reverse gear is selected if the last drive position was DL (Drive Low) or D2 (Drive 2) which are used in off-road driving.

4.7.3.7. Speed sensor fault tolerance. Control of the transmission is based upon information derived from sensors monitoring the speed of the engine, transmission input shaft, and transmission output shaft. Peak performance of the system can only be obtained when all three of these sensors are functioning properly. In the previous system, the information from these sensors was continuously checked for validity. If the information from any sensor was found to be invalid, all shifts were inhibited, and the vehicle was allowed to operate in the present gear until it came to a stop.

The new system continuously monitors the validity of the information from the sensors, as did the previous system; however, in the event that the information is found to be invalid, the new system replaces the invalid data with best estimates based upon information received from the valid sensors. As a result, the transmission system remains operational, albeit with reduced performance, with any single-point speed sensor failure. A simultaneous failure of two or more speed sensors will result in the system inhibiting all shifts as in the previous system.

4.7.3.8. Electronic engine control interface. An interface to an electronic engine control system has been designed and implemented in the transmission control unit. This interface provides a Pulse Width Modulated (PWM) signal which can be connected to an auxiliary throttle input on a John Deere engine electronic control unit. The foot pedal sensor normally used with this electronically controlled engine is not used. The foot pedal sensor used by the transmission system remains connected to the transmission control unit. The transmission control unit then provides all throttle inputs to the engine controller through this interface. The D.C. gear motor actuator normally used with this transmission system with mechanical fuel pumps as described in 4.7.3.2. is not required.

A second electronic interface with the engine is also provided to allow the transmission to select one of two torque curves. This interface is used by the transmission to select a level

of engine torque based upon the transmission reduction ratio that will be safely handled by the rest of the driveline when multiplied by the transmission gear ratio.

4.7.3.9. Available options. The use of a drive-by-wire fuel control allows additional features of the transmission system to be available as options. These options, which are implemented in the commercial counterpart of this transmission system, include cruise control and road speed governing.

Cruise Control is a speed control system available as an option on this transmission. Cruise Control maintains a constant forward speed during most highway and some off-road driving without the driver keeping his foot on the accelerator pedal, thus increasing driving comfort on long trips.

Road Speed Governing is also available as an option on this transmission. Road Speed Governing limits the top speed of the vehicle independent of the engine governor and vehicle gearing. The top speed limit is preset at the factory and cannot be changed by the user. The Road Speed Governor allows the vehicle to be geared in a "gear fast, run slow" configuration for improved fuel economy in on-highway operation and provides the assurance, by design, that the vehicle will not be operated at unsafe or fuel-inefficient speeds.

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Olson, O. "*Evaluation Study and Preliminary Truck Testing of an Automatic Control System Concept for a Mechanical Transmission*," Eaton CoRD - Detroit Center Technical Report No. 82085, 1982, for contract DAAE07-81-C-4054.

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APPENDIX A

PRODUCT LITERATURE AND OPERATION

OF THE

EATON FULLER "CEEMAT™" TRANSMISSION

EATON FULLER CEEMAT™ TRANSMISSION

INTRODUCTION

Eaton Corporation has invested in developing automated mechanical transmissions with automated conventional dry clutches for its existing markets of commercial trucks in normal on-road applications.

In this contract with TACOM, the feasibility of applying this development towards the on-off road requirement of military tactical trucks was evaluated with reasonable success in reaching both the performance and durability goals.

The traditional approach in automatic transmissions has utilized a hydrokinetic device, fluid coupling or torque converter, as the coupling between the gearbox and the engine flywheel. The success of this approach is well known, and its use in construction, on-off road, military and start-and-stop applications well documented.

As a business as well as a technical decision, Eaton Corporation has decided to compete in these same applications with a torque converter between the automatic mechanical transmission and the engine flywheel. The transmission model is called CEEMAT—"Converter Enhanced Electronically Managed Automatic Transmission." Production of the CEEMAT transmission will begin in September 1988 for application in front discharge mixers (concrete). A detailed description of the transmission follows.

TECHNICAL DESCRIPTION

The design strategy was to select one of Fuller's line of manual transmissions intended for on and off highway service and to automate it.

In view of the fact that the Roadranger transmission is not used in military vehicles yet, and that its most distinguishing feature, its twin countershaft design, is not familiar to most readers, we have included some basic information on this transmission from Eaton's sales and service literature. The next page is a current sales brochure illustrating the essential features of the 9-speed, on-off series. This series includes the one used as the nucleus of the CE2MAT. The suffix "B" denotes an extended range of gear ratios for off-road applications. Note that, for this transmission series, the overall ratio coverage is 17.21 [$12.56 \text{ (low)} \div 0.73 \text{ (high)}$]. This single range of nine forward gears has never before been available to military vehicles. We would also mention here that the Roadranger series has acquired a thirty-year history of dependability in commercial applications all over the world. There are now 1.1 million of them in services, of which 250,000 are nine-speeds.

Following the brochure are two pages of excerpts from one of Eaton's service manuals. At the top of the first page is a view of the transmission, showing the twin countershafts flanking the mainshaft. This design was developed as a method of reducing the length of the transmission, but it also contributes much to the transmission's extraordinary performance and durability. Following this view is a description of how driveline power is transmitted through the countershaft arrangement. Material such as this is immediately available to the Army for training its mechanics on the CE2MAT.

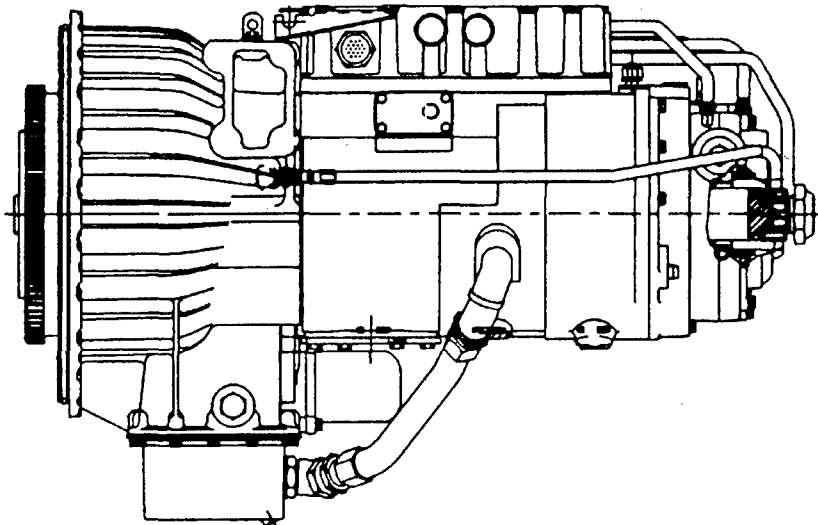
Eaton® Fuller® Transmissions

CEEMAT™ Converter-Enhanced Electronically Managed Automatic Transmissions

**The heavy-duty automatics with
a Roadranger heritage.**

Features

- Proven Roadranger Transmission performance capable of handling various engines up to 475 hp and 1450 lbs.-ft. torque.*
- Offers state-of-the-art electronic technology with the reliability of the Roadranger twin counter-shaft design.
- Broad ratio coverage and micro-computers combine for smooth, progressive shifts made automatically.
- Ratio coverage enhances off-road performance and reduces external cooling requirements.
- Roadranger-based modular design for ease of maintenance as well as operation. Electronic repairs can be done in-frame.
- Spline driven torque converter eliminates costly installation procedures.



* 600 HP and 1650 Lbs.-Ft. with approval.

Notice: This is an "early release" sales sheet. Specifications, ratios and capacities are subject to change at any time without notice.

EAT•N

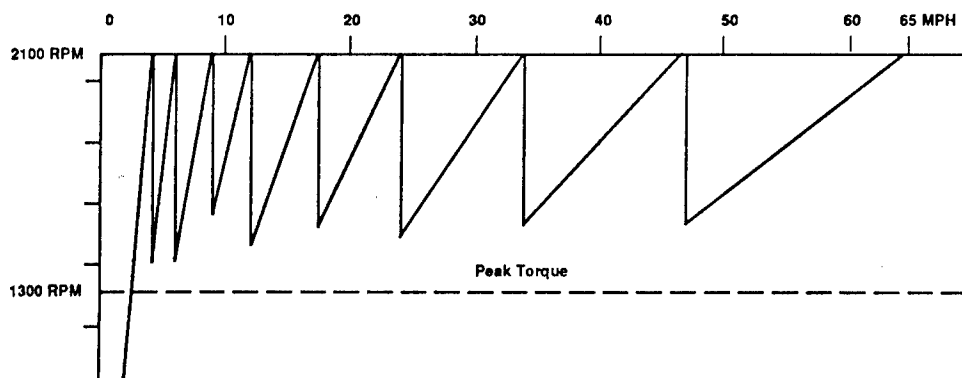
Eaton Fuller CEEMAT Roadranger Transmission Specifications.

CEEMAT SPECIFICATIONS :		RTO-9109B-AT	RTO-12109B-AT	RTO-14109B-AT
Rating	Nominal Power Rating	300 HP	370 HP	475 HP
	Input Speed, Full Load (Governed)	2800 RPM	2400 RPM	2400 RPM
	Nominal Torque Rating	975 Lbs.-Ft.	1250 Lbs.-Ft.	1450 Lbs.-Ft.*
Mounting	Engine	SAE#2 Housing One Vertical Mtg. Pad Each Side		
Torque Converter	Type	Single Stage, 3 Element, 2 Phase		
	Stall Torque Ratio	2.2:1		
Oil System	Oil Type Filtration Pressure Lube	Mil L-2104D C3 Type Fluids/Grade 10W Integral, High Pressure Filter Gear Driven @ 1.18 X Engine Speed		
	Capacity	9 gals.	10 gals.	11 gals.
Size	Length**	35.9 in.	36.4 in.	37.0 in.
	Weight (Approx.)	1000 Lbs.	1020 Lbs.	1040 Lbs.

Gear	Ratio	% Step
9	.73	37
8	1.00	38
7	1.38	41
6	1.95	43
5	2.79	37
4	3.83	38
3	5.28	41
2	7.47	68
1	12.56	
Rev	13.14	

* Applications to 600 HP and 1650 Lbs.-Ft. available with engineering approval.

** SAE flange to end of output shaft spline.



Eaton Roadranger service keeps you on the road.

For more information contact your regional Eaton Roadranger sales and service office at 1-800-TCM-HELP. In Canada, call 1-800-387-3935.

EATON

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For more information on all Eaton Fuller Transmission products, contact : Eaton Corporation
Transmission Division
P.O. Box 4013
Kalamazoo, MI 49003
(616) 342-3344

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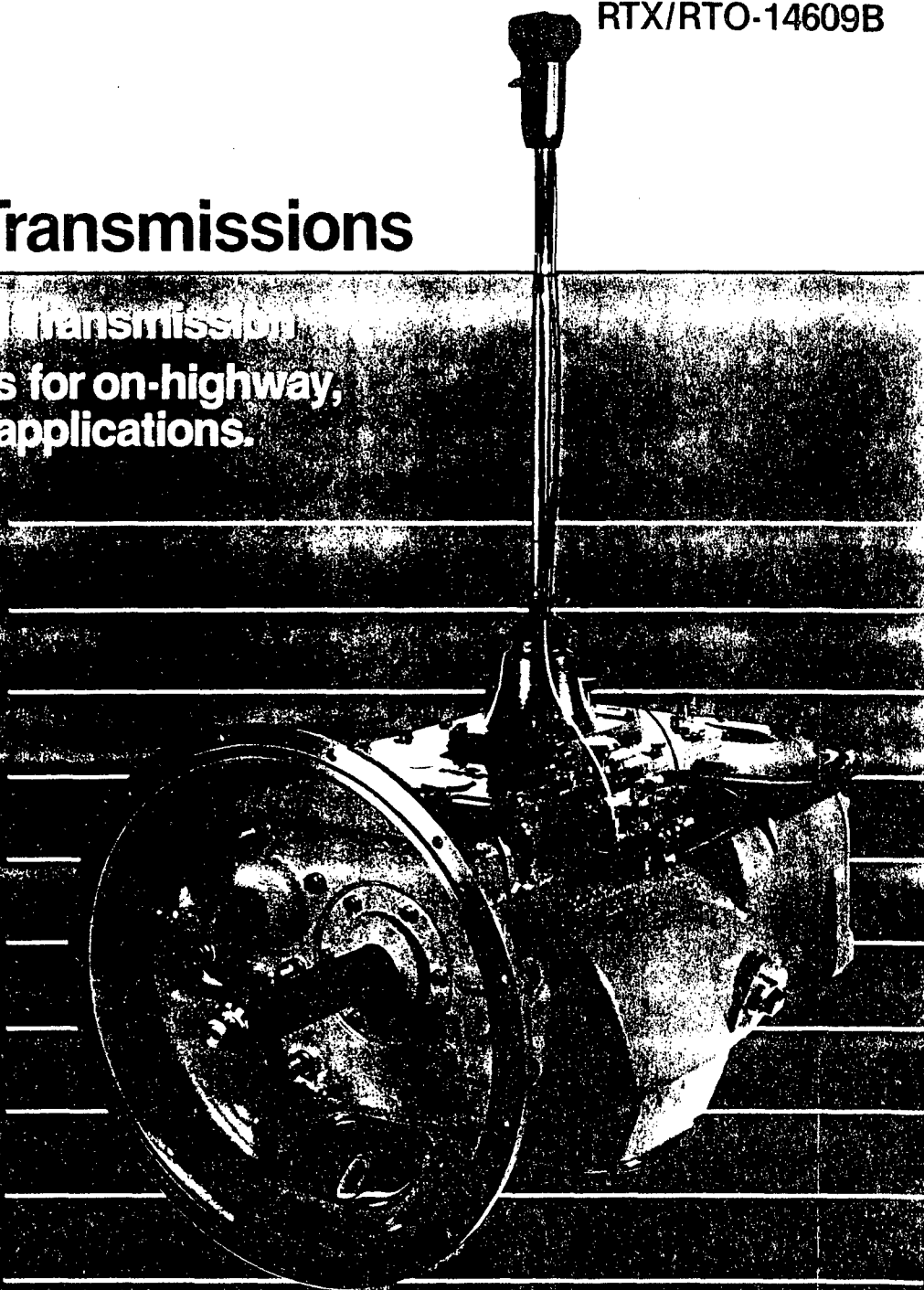
Eaton® Fuller® Transmissions

The B-Ratio 9-Speed Transmission

Specialized 9-speeds for on-highway,
and on/off-highway applications.

Features

- Proven Roadranger® Transmission performance capable of handling various engines up to 450 hp and 1450 lbs.-ft. torque.
- Multi-Mesh™ gearing for quieter power flow, longer gear and bearing life.
- Front box mounted oil trough for improved lubrication.
- Improved end yoke and seal designs ensure longer sealing life.
- Air system features corrosion-resistant range air valve and filter/regulator mounted directly on transmission.
- Proven heavy-duty synchronizer technology offers easy range shifting and long life.
- Simple repeat shift pattern. RTX overdrive model uses direct shift pattern.
- No special tools or training required for maintenance.



EAT•N

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Eaton Fuller RTX-11609B, RTX-12609B, RTX-14609B Roadranger Transmission Specifications.

Speeds:

9 forward, 2 reverse.

Capacity:

RTX-11609B — up to 370 hp, 1150 lbs.-ft. torque.
RTX-12609B — up to 370 hp, 1200 lbs.-ft. torque.
RTX-14609B — up to 450 hp, 1450 lbs.-ft. torque.

Weight: (less clutch housing)

RTX-11609B — 590 lbs.
RTX-12609B — 602 lbs.
RTX-14609B — 616 lbs.

Length:

RTX-11609B — 28.9 in.
RTX-12609B — 28.9 in.
RTX-14609B — 29.5 in.

Power Take-Off Openings:

2 SAE standard openings.
Right side, regular-duty, 6-bolt.
Bottom, heavy-duty, 8-bolt.
Thru-shaft PTO also available.

PTO Drive Gears:

Right side, a 45-tooth, 6/8 pitch gear.
Bottom, a 47-tooth, 6/8 pitch gear.
Right side, bottom and thru-shaft PTO gears turn at .788 engine speed.

Oil Capacity:

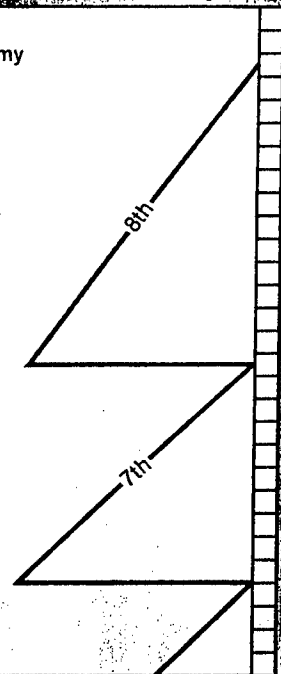
Approx. 27 pints.
Always fill to level of filler opening.

RTX-11609B, RTX-12609B, RTX-14609B

Gear	Ratio	% Step
8	.73	37
7	1.00	38
6	1.38	41
5	1.95	43
4	2.79	37
3	3.82	38
2	5.28	41
1	7.47	68
Low	12.56	
Hi Reverse	3.43	
Lo Reverse	13.14	

Performance Plus Economy

Fuel
Economy
Range



Simple Repeat
Shift Pattern



RTX Shift Pattern
(Changes overdrive
shift pattern to a
more efficient pattern)

Eaton® RoadrangerSM service keeps you on the road.

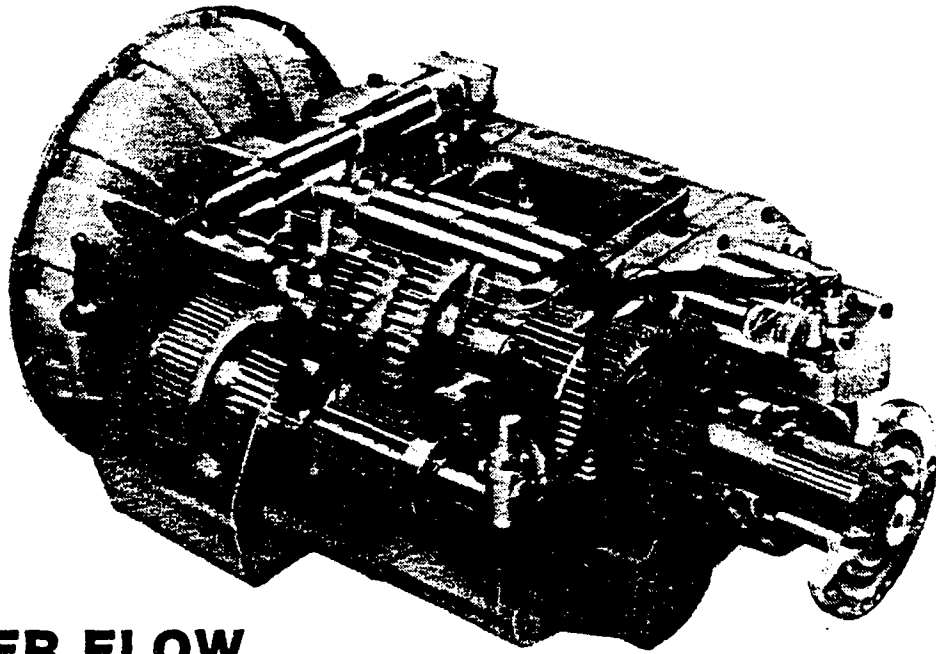
For more information contact your regional Eaton® Roadranger™ sales and service office at 1-800-TCM-HELP. In Canada, call 1-800-387-3935.

EATON

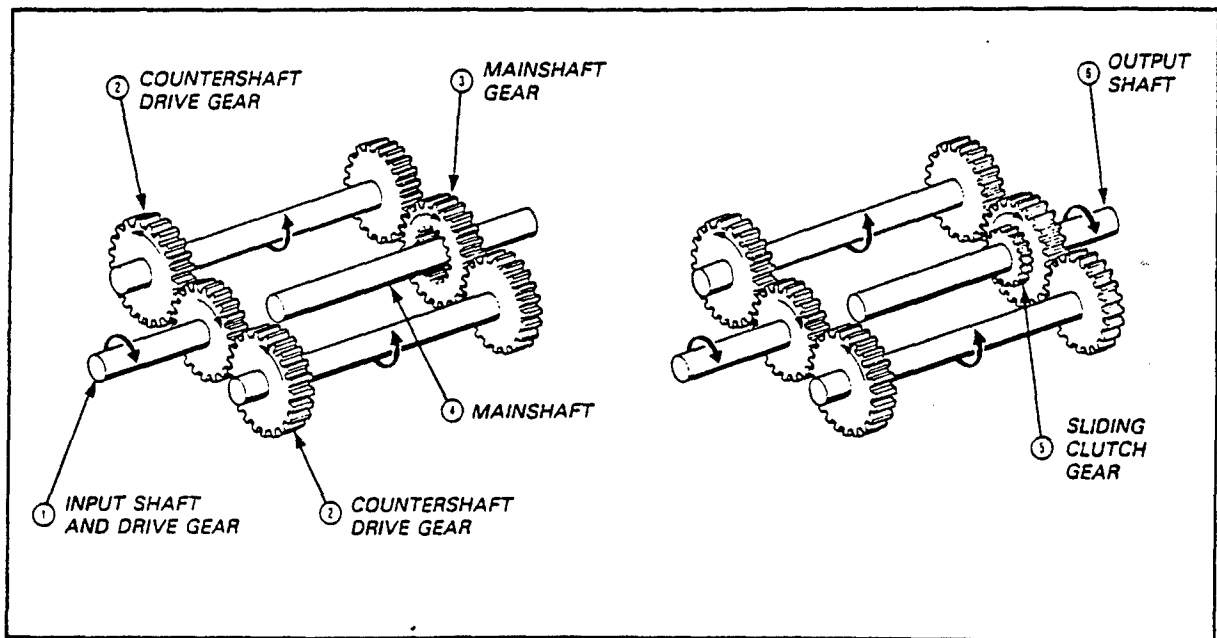
For more information on all Fuller Transmission products, contact:

Eaton Corporation
Transmission Division
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POWER FLOW



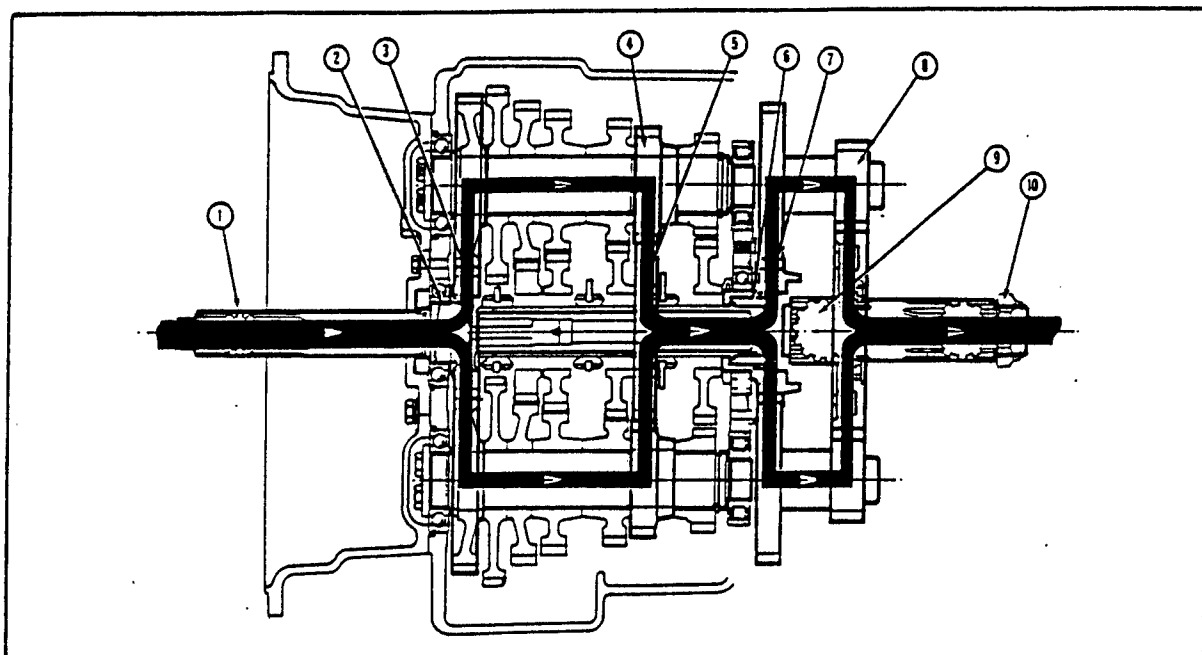
A simplified diagram of the power flow through a Fuller twin countershaft transmission will help show how torque and speed are changed, and how torque is divided between the two countershafts.

The input shaft and drive gear (1) are in constant mesh with both countershaft drive gears (2); when the input shaft turns, the countershafts turn. The countershaft gears are in constant mesh with the "floating" mainshaft gears (3). The mainshaft gears are simply free-wheeling on the mainshaft (4). A slid-

ing clutch gear (5), which is splined to the mainshaft, is engaged into the internal clutching teeth of the mainshaft gear, coupling it to the mainshaft. The mainshaft will now be turning at the selected gear ratio.

Fuller twin countershaft Roadranger® transmissions commonly consist of a five speed front section and either a two or three speed auxiliary section, both in one case.

POWER FLOW (con't.)



1. Power (torque) from the engine flywheel is transferred to the input shaft.
2. Splines on input shaft engage internal splines in hub of drive gear.
3. Torque is split between the two countershaft drive gears.
4. Torque delivered by two countershaft gears to mainshaft gear which is engaged. Diagram shows first speed gear engaged.
5. Internal splines in hub of mainshaft gear transfers torque to mainshaft through sliding clutch gear.
6. Mainshaft transfers torque to auxiliary drive gear through a self-aligning coupling gear located in hub of auxiliary drive gear.
7. Torque is split between the two auxiliary countershaft drive gears. (In direct drive or high range, power is delivered to the output shaft from the auxiliary drive gear through a self-aligning sliding clutch gear.)
8. Torque is delivered by the two countershaft low range gears to the low range gear.
9. Torque delivered to output shaft through self-aligning sliding clutch gear.
10. Output shaft is attached to drive line.

Transmission Subsystems

Figure 1-1 illustrates the housings for the major subsystems of the CE2MAT and the way they are combined to form the finished transmission. Figure 1-2 is a cross-sectional view showing in more detail the automation subsystems and their locations relative to the main transmission box. Automation of the CE2MAT is accomplished electronically. The Electronic Control Unit (ECU) senses vehicle speed and the positions of the throttle and shift lever, and it manipulates the clutch, throttle, the power synchronizer, and the transmission shift rails to change gear ratios as the road load demands. But before we can describe this electronic automation in more detail, we must first introduce the major subsystems on the CE2MAT and describe their principal functions.

Transmission Box. This is the 9-speed 11609B described in the brochure, but stripped of its shifting apparatus. Since the transfer case to be used with the CE2MAT is a single speed unit with a 1:1 ratio, the ratios specified for the transmission will apply to the entire drivetrain.

Torque Converter. This device reduces the wear on many of the drivetrain components by providing a smooth start and smooth transitions through the gears. It extends ratio coverage by multiplying torque by a factor of 1.6 at 80% efficiency. This extension allows every shift to be delayed until the ECU determines whether or not it is absolutely required, thereby eliminating unnecessary shifts whenever conditions hover about a shift-threshold. The smoothing effect of the torque converter also provides the vehicle with inching control.

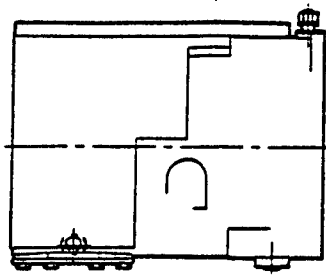
Interrupt Clutch. This is a multidisk, wet pack clutch which uncouples the transmission from the torque converter and/or the engine in the lock-up mode. The clutch is engaged when the shift lever is first placed in drive. The wet environment and the smoothing action provided to this clutch by the torque converter considerably simplify its design and manipulation. The clutch is controlled by the ECU by means of a solenoid-activated hydraulic valve and trimmer valve. These features account for the durability of the interrupt clutch.

By-pass Clutch. This is a single-disk, wet pack clutch which is engaged by the ECU to lock the engine directly to the input shaft. When engaged, the clutch bypasses the torque converter and its hydro-kinetic losses, thereby optimizing transmission efficiency. Control of this clutch is by means of a solenoid-actuated hydraulic valve and trimmer valve.

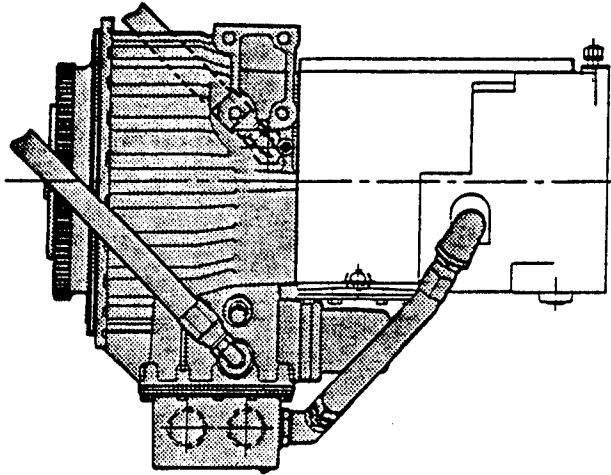
Power Synchronizer. By feeding kinetic energy from the output shaft, the power synchronizer speeds up or slows down the front box to synchronize ratios. It accomplishes this action by means of two brakes. The Up-shift Brake retards the input shaft. It is capable of shaft decelerations of 3,000 rpm/sec. The Downshift Brake stops the ring of a planetary, which in turn speeds up the input shaft. Normal engine acceleration is from 750 to 1,000 rpm/sec, but the Downshift Brake can create acceleration rates up to 3,000 rpm/sec.

The action of the power synchronizer is controlled by the Electronic Control Unit by means of two solenoid-actuated air valves.

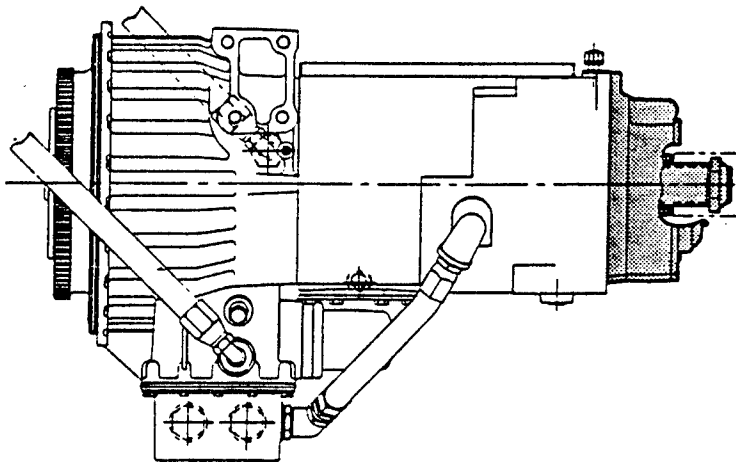
Auto-shifter. This device provides the force for fore and aft mainshaft clutch engagement and disengagement for each front box gear position. It consists of two, 3-position



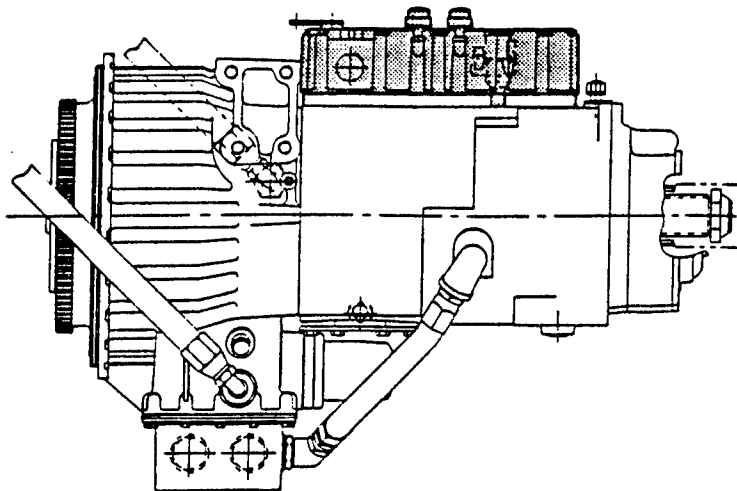
Main transmission box consisting of a 5-speed front box and 2-speed rear box (range shifter).



Torque Converter for smooth, durable starting • Interrupt and bypass clutches • Wet environment.



Power Synchronizer allows rapid shift at engine accel. rates up to 3000 rpm/sec.



Auto-Shifter to do the actual shifting and an ECU and network to control it all.

Figure 1-1. Stages in the development of the CEE MAT.

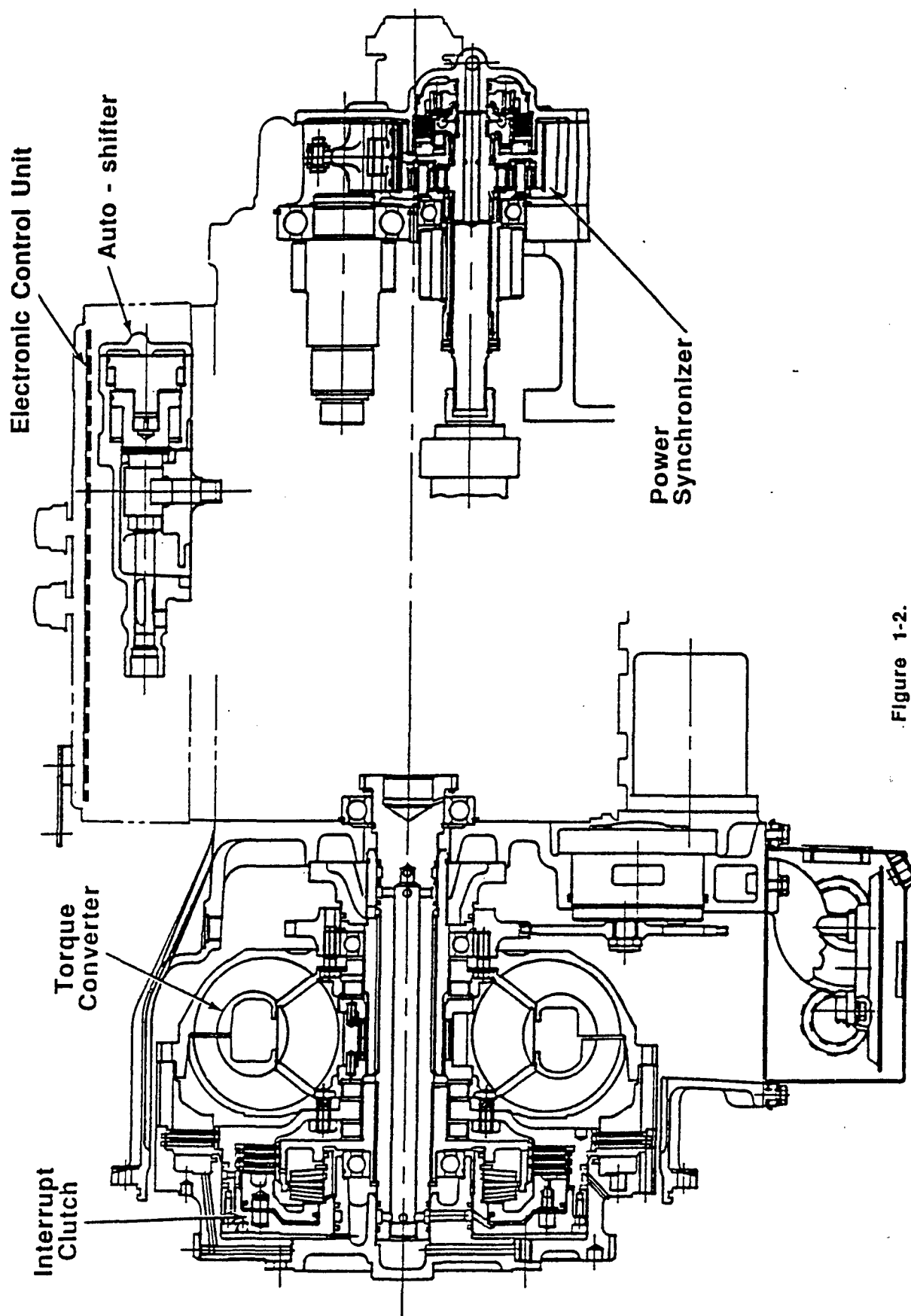


Figure 1-2.

actuators in an X-Y configuration. The actuators are driven by air supplied by the engine's air compressor. Air pressure to the actuators is controlled by the ECU by means of four solenoids.

Electronic Control Unit (ECU). This device consists of a 9 X 13 inch, multilayered printed circuit board mounted atop the main transmission box. From various sources it receives information as to range, speed and status. With this data it makes calculations and decisions, and it implements those decisions by means of control solenoids. The solenoids, which are electromagnets, in turn actuate pneumatic or hydraulic valves. The microprocessor used in the transmission ECU is Intel's 8051. It is a relatively simple, common microprocessor with a history of high reliability in automotive applications. The entire ECU is protected for electromagnetic interference and high altitude EMP by an aluminum cover and a lot of printed circuit board ground plane.

Oil Pump. An external, gear-type oil pump provides the hydraulic pressure and flow for clutch actuation and torque converter cooling.

Cooling flow from the torque converter is at least 9 gpm at 1800 rpm engine speed, plus at least 2 gpm is diverted to the main transmission. Approximately 0.8 gpm of the 2 gpm is delivered to the power-synchronizer; the remainder is for gear and bearing lubrication. An internal oil filter capable of handling 20+ gpm provided clean oil to the hydraulic valve. The external hose connections to the CE2MAT shown in Figure 1-1 are for torque converter cooling oil connections.

Air Requirements. The air supply should be dehydrated and screened for contaminants. As with the brakes, the transmission should have priority of air use over other systems such as a Central Tire Inflation System.

Figures 1-3 shows the aluminum cover raised and its contents – the auto-shifter and the ECU – exposed. The ECU is anchored on standoffs to the underside of the cover; the auto-shifter is mounted on the deckplate. The wire-runs and harnesses around the ECU are a feature of the prototype only. On the production version they will be entirely replaced by another layer of printed circuit board containing wire traces.

All electrical connections to the ECU are made through the single bayonet-type connector in the forefront of the housing. Air is supplied to the pneumatic valves of the auto-shifter through a connector on the right side of the cover.

The ECU is located on the transmission itself, rather than in a more protected environment such as the cab. One reason is that it requires fewer and shorter wire runs than would a remote ECU. This in turn reduces costs, installation time, electromagnetic susceptibility. Furthermore, Eaton has control over the quality and integrity of the system's installation. The system would be assembled and completely tested as a unit by Eaton. The heat and vibration atop the transmission box are no longer obstacles to electronic controls. The ECU is certified for operation to 125°C (257°F), and it has survived a battery of environmental tests for design verification.

System Operation

A block diagram of the electronic management system for the transmission is shown in Figure 1-4. In this illustration we have, so to speak, lifted the aluminum module cover and

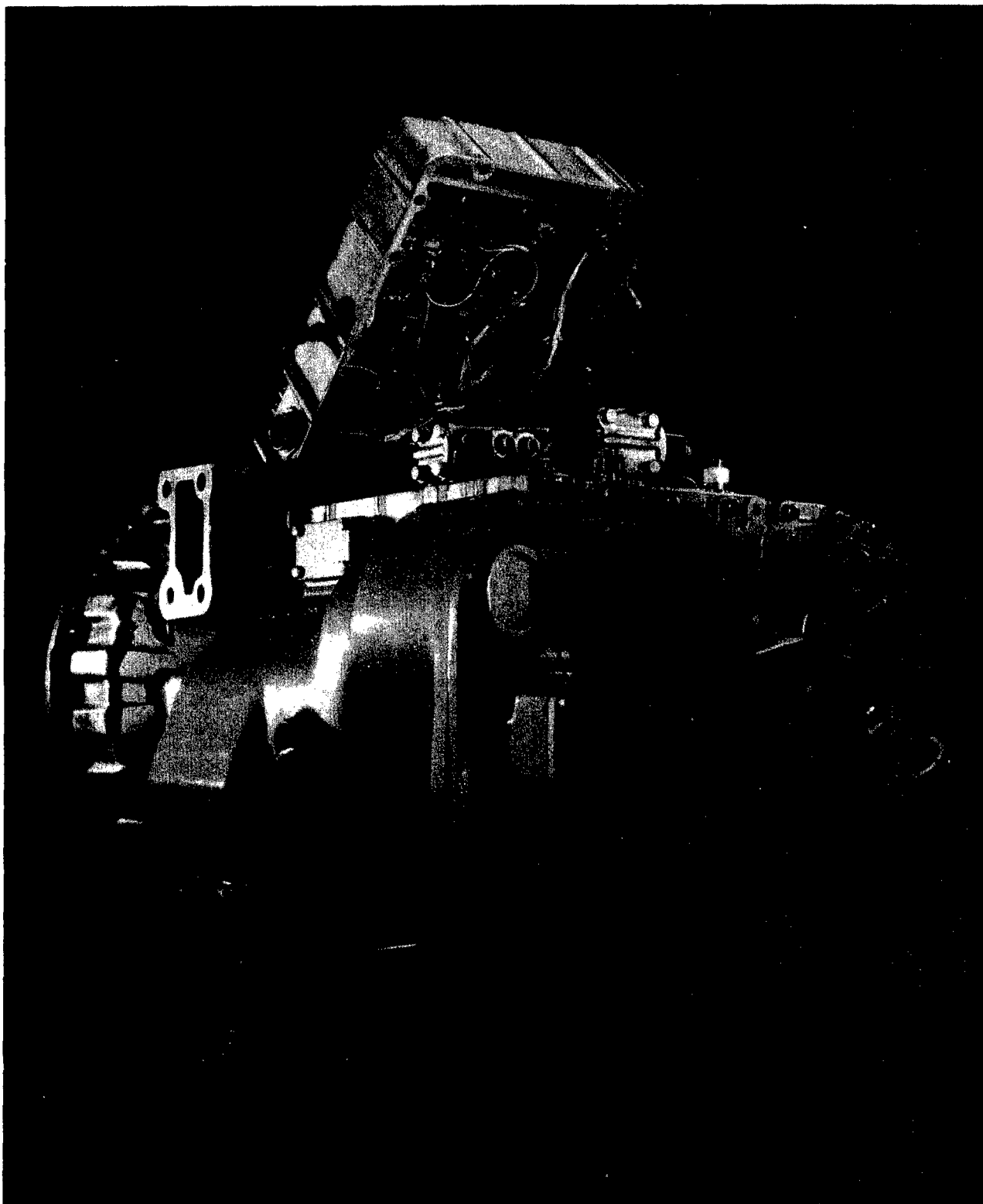
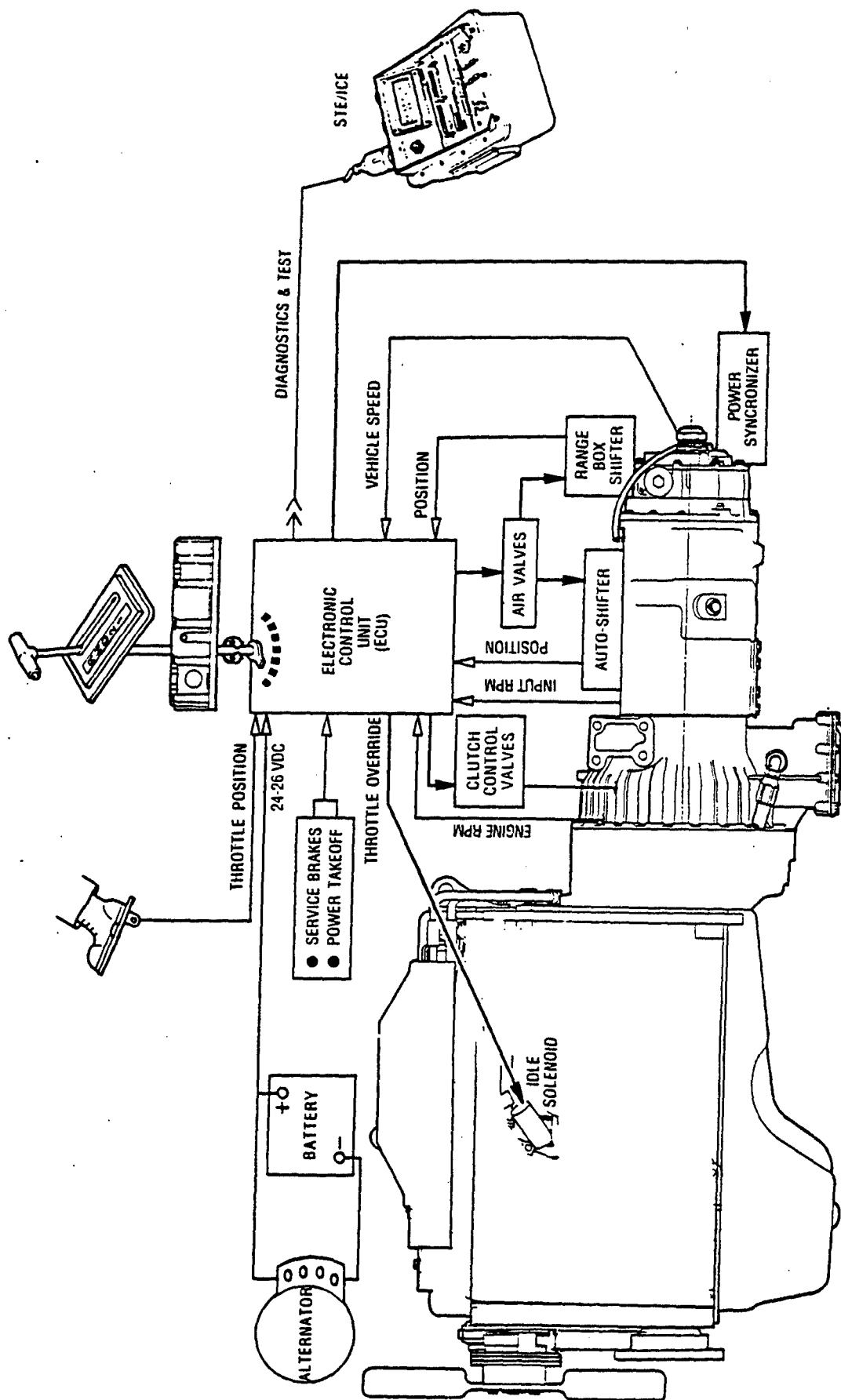


Figure 1-3

FIGURE 1-4



identified its contents and their interconnections. In general, a lightweight line and a hollow arrow designates one or more electrical conductors carrying something to the ECU, such as power or information in the form of electrical signals. A heavy line and solid arrow designates electrical conductors control signals from the ECU – signals which energize solenoids and thereby perform some sort of action.

Electrical Power. The ECU has redundant power sources and power cables. Normally, power is supplied by the engine alternator. If the alternator fails, the ECU will automatically draw power from the vehicle battery.

Shift-Lever Position. The location and function of the shift tower with the new drive train will remain unchanged. The positions of the shift lever and the corresponding gears selected for the CE2MAT are as follows:

Shift Lever Position	Gear Ratio
R	13.14:1
N	—
	0.73:1
	1.00:1
	1.38:1
D	1.95:1
	2.79:1
	3.82:1
	5.28:1
	(Will downshift to 7.47:1)
2	7.47:1
1	12.56:1

When the driver shifts, the lateral motion which he applies to the shift lever is translated into the rotational motion of a shaft. The shaft extends down through the floor of the cab, through the aluminum module cover, and terminates just above the ECU board. Attached to the end of the shaft is a permanent magnet, which sweeps a semi-circular array of Hall-effect switches on the board. There is one switch for each position of the shift lever (and two spares). A Hall-effect switch is a solid-state device which closes in the proximity of a static magnet field. By means of these switches, the ECU is informed of the driver's selection of shift position. (Like any switch, a Hall-effect switch translates a mechanical state into an electrical state. Hall-effect switches are used in this particular application because they do it with extreme reliability. They have no mechanical parts to fatigue and break, no contacts to foul).

Throttle Position. By means of a radial potentiometer connected to the throttle pedal, the ECU is continuously informed of the exact position of the throttle.

Engine RPM, Input Speed, Output Speed. Three magnetic speed pickups inform the ECU of engine RPM and the shaft speeds at the input and output of the main box. From output shaft speed, the ECU derives vehicle speed.

Clutch Controls. These consists of two solenoid-operated hydraulic valves. Actuation of one will engage the main (Interrupt) clutch. Actuation of the other will engage the torque converter lock-up clutch.

Throttle Override. Actuation of the idle solenoid will cut fuel to the engine and facilitate smooth up-shifts.

Auto-Shifter Controls. To shift the transmission, the ECU actuates a combination of four solenoid-operated pneumatic valves. Gear positions are in turn monitored by the ECU by means of three switches located on the autoshift.

Range Box Control. One solenoid-operated air valve is used to select the transmission range. When the solenoid is energized, low range is selected. Two switches in the Range Box Shifter give the ECU a positive indication of which range the range box is in.

Power Synchronizer. The power synchronizer mechanism is activated by two solenoids which either increase or decrease the speed of the front gear box input shaft.

Service Brakes & P.T.O. Two switches, one for each function, inform the ECU as to the status of these devices - i.e., engaged or disengaged.

WHY A TORQUE CONVERTER:

The CEEMAT:

Eliminates the concern about dry clutch wear in an on/off highway application of an AMT type transmission. No wear compensation devices are required in the CEEMAT T/C or clutch, nor are maintenance routines requires.

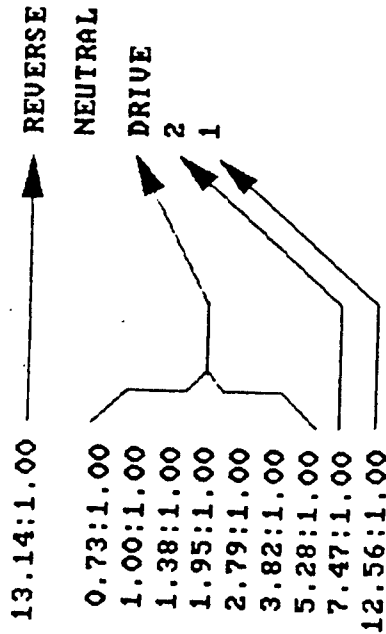
The CEEMAT:

Eliminates elaborate software routines and more complex throttle control devices which are required to modulate both the clutch and engine fuel during vehicle starts in the AMT system. The AMT system uses a fly-by wire engine fuel control which electronically applies the throttle during downshifts. The CEEMAT system simply turns on the clutch when drive is selected and the operator applies the throttle to move the vehicle. The throttle is closed during shifts in the CEEMAT system and then returned to the driver's demand. At no time is the throttle ever increased beyond the driver's demand.

The CEEMAT:

Eliminates the driver's need to depress the throttle to engage the clutch to inch the vehicle as in the AMT system. In the CEEMAT system, the torque converter applies a low level of torque to the driveline when the shift lever is placed in "D". The CEEMAT will allow the driver to smoothly modulate the torque with the throttle and easily create very high levels of thrust such as would be required to negotiate a stepped obstacle or to pull out of a deep rut. In the AMT system the high torque slip time is very limited and the torque level cannot exceed engine fuel torque; therefore, additional ratio must be provided in the gear train to create the same thrust as a torque converter enhanced transmission. If the AMT equipped truck moves too quickly, the driver must depress the brake which he probably does with the right foot. (The throttle pedal foot.) With the throttle back at zero, the clutch disengages. To resume motion, the driver must reenter the restart routine by depressing the throttle again.

CE²MAT SYSTEM



DRIVER INSTRUCTIONS:

Select Drive for normal driving.
 Select "2" for extra pull at low speeds.
 Select "1" for starting on very steep grades.
 Select "R" for Reverse.
 To inhibit upshifts for downhill engine braking, move the gear selector to "2".
 For maximum downhill engine braking, move the shift lever to "1" and operate the vehicle below 3 mph.

DESCRIPTION OF OPERATION:

Movement from neutral to Drive will cause the transmission to engage the 5.28 ratio which is the normal starting ratio. The torque converter is open in 5.28 ratio and the driver feels the pull to start. As he depresses the throttle, the engine will speed up increasing the slip across the torque converter causing more torque to be generated, hence more pull. As the vehicle accelerates, the electronics monitors the output speed and at the proper time initiates an upshift to 3.82 ratio. Subsequent shifts to 2.79 follow suit. In 2.79, the electronics will engage the torque converter lockup clutch. Shifts into 1.95 ratio, 1.38 ratio, 1.00 ratio and 0.73 overdrive ratio follow and remain in lockup. As the vehicle slows down, the electronics will perform the downshifts as a function of speed and throttle setting. Full throttle downshifts will be evaluated by the electronics for slip across the torque converter to determine if skip downshifts should be performed. Skip down shifts can be made from the 1.38, 1.95 and 2.79 ratios. (See Attached Table)

If the driver moves the shifts lever to "2", then full throttle downshifts to the 7.47 ratio can be made in a small window of speeds. Below 800 rpm turbine speed in the 5.28 ratio, downshifts will not be performed until the driver steps on the brake. Downshifts to 12.56 ratio in the "1" position will not be performed until the brake is applied.

There is a speed limit on reverse engagements, yet the driver can effectively rock the vehicle by moving the shift lever from reverse to drive.

ADDITIONAL FEATURES:

Retarder Operation: The transmission control is wired into the retarder to hold lockup in all ratios. The retarder is turned off momentarily when the transmission needs to be shifted, then retard operation is returned when the new ratio is engaged. Additional retard capability is available in "2" and "1" shift lever positions.

PTO Operation: When the PTO is engaged in neutral, the transmission will engage the interrupt clutch to power the PTO gears while the transmission remains in neutral.

Vehicle Towing: The transmission will tolerate towing even if the driveshaft is not disconnected. To do so, the operator must be sure that the Master electrical switch is turned off and that air pressure (a minimum of 35 psi) is available to the transmission.

Minimum Cooling: Transmission cooling requirements can be minimized by selecting shift lever position "2" or "1" which forces downshifts at the earliest possible speed and creates torque converter lockup in all gears.

Downshift Rules For the CR²MAT

In 1.38 Ratio

If Torque Converter Slip > 500 RPM, and Decel > 20 Downshift to 2.79
and Decel > 30 Downshift to 3.82
and Decel > 50 Downshift to 5.28

Else, Downshift to 1.95

In 1.95 Ratio

If Deceleration During Range Shift > 13, Downshift to 3.82
or if Decel > 22, Downshift to 5.28

Else, Downshift to 2.79

In 2.79 Ratio

Always Downshift to 5.28

In 3.82 Ratio

Always Downshift to 5.28

In 5.28 Ratio

Allow Downshift to 7.47 If:

Lever is Placed in "2" and

Input Speed is Between 900 RPM and 800 RPM or

If the Brakes are Applied and Input Speed is Below 800 RPM

Otherwise:

To Get 7.47 Ratio, Place Lever in "2", Apply the Brakes Until
Vehicle Slows to the Downshift Point.

To Get 12.56 Ratio, Place Lever in "1", Apply the Brakes Until
Vehicle Slows to the Downshift Point.

APPENDIX B

EATON PROVING GROUNDS
TEST PLAN AND DATA SHEETS

R E V I S E D D R A F T
April 10, 1985

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

I. Contract Summary:

The contractor, as an independent contractor and not as an agent of the government, shall provide the necessary material, labor, facilities and technical expertise to adapt a mechanical transmission, Model TSO-11616 Twin Splitter with integral transfer case to meet the United States Army requirements as listed in Attachment 1 for a five-ton M-939 series truck.

II. Test Plan Objective:

The transmission system has been designed, fabricated, and installed in a M-923, 6x6, cargo truck, a member of the 5-ton M-939 series of tactical trucks.

This test plan will specify the required tests to verify that the performance goals of the five-ton, M-939 series truck are achieved.

In addition, the basic transmission function and features will be documented and reported.

The performance goals are attached to this test plan.

III. Description of Test Item

The Eaton Automated Mechanical Transmission (AMT) is the combination of a mechanical transmission which was originally designed to be operated manually by the driver, electronic controls and pneumatic actuators in order to create a fully automatic transmission.

Attachment - Page 2

In order to automate a mechanical transmission which is normally operated directly by the driver, the engine, clutch, transmission and electronic logic become a system which controls vehicle starts and transmission shifting.

Activating mechanisms must be added to replace the driver's hand and foot operations, and a controller or electronic logic must replace the driver's decision-making process. Such a system is illustrated by the schematic diagram shown in Figure 1.

The additional components required to complete the system are as follows:

1. Cab lever control for driver input.
2. Clutch control mechanism for engaging and releasing the master clutch.
3. Input brake for shift synchronization.
4. Throttle mechanism for fuel control for manipulation of the engine independent of the driver.
5. Main box and auxiliary box shifter mechanisms to engage the desired gear.
6. Air valve manifold with solenoid operators to actuate the brake, clutch and shifters.
7. Electronic logic control to operate the complete system.

To provide the all-wheel drive function of the transfer case, an integral drop box is added to the base TS0-11616 transmission.

IV. Approach to Test Plan

The M-923 6x6 truck with the AMT will be taken to Eaton's Proving Grounds in Marshall, Michigan. An M-345, pintle type trailer is available for test use as may be required.

The Eaton Proving Grounds has the following facilities to be used in performance of this test plan.

1. Weights and vehicle scale for documentation of GVW or GCW.
2. 1.6 Mile paved oval track.
3. 1050' x 200' skid pad with various coefficient surfaces.
4. Paved test grades of 20% and 60%.
5. Gravel test grades of 5%, 10%, 15%, 20%, 25%, and 30%.
6. Secondary roads.
7. Cross country test areas which are wooded, rocky and hilly.
8. Test garage.
9. Fuel available on site.

Prior to the performance of the tests, the truck will have accumulated in excess of 1,000 miles to assure adequate performance of the system components.

Specific tests will be defined in order to measure the test truck's performance in comparison to specific performance goals.

The tests shall be repeated a specified number of times in order to diminish outside influences, (wind velocity, for example) from assisting in achievement of the goal.

An individual test sheet will be prepared for each test to allow recording of test parameters, i.e. date, time, temperature, axle weights, equipment used, etc. as well as defining the pass/fail criteria. Upon completion of the test, the test sheet will be signed by the Eaton engineer and the TACOM representative.

V. Specific Tests

A. High Speed - Ref: Performance Goal 12.0

Vehicle Load - 50,000 lbs GCW with towed load.

Requirement - Operate at a sustained high speed of not less than 50 MPH

Equipment Required - a) M-345 Pintle Trailer, b) Calibrated fifth wheel for accurate speed measurement.

Method - Record minimum and maximum speeds over each of five laps (8 miles total) of proving ground's oval track, after transmission is in high gear (16th). Repeat twice.

B. Low Speed - Ref: Performance Goal 13.0

Vehicle Load - Not specified

Requirement - Operate at a sustained low speed of not more than 2-1/2 MPH without damage to the vehicle.

Equipment Required - Calibrated fifth wheel

Method - Record ambient temperature and engine water and transmission oil temperatures as test run is started. Drive in low gear (1st) for 2 miles (48 minutes) and record the engine water and transmission oil temperatures every 10 minutes until completion of test. Repeat twice.

C. Gradeability on 60% Slope - Ref: Performance Goal 18.0

Vehicle Load - 10,000 lb. payload

Requirement - Negotiate a 60% grade at a minimum speed of 2-1/2 MPH. The grade surface shall be smooth dry concrete.

Equipment Required - Instrumentation package to verify engine speed for vehicle speed calculation.

Method - The 60% grade will be negotiated twice. On the second time, the vehicle shall be stopped and the engine shutdown. After two minutes, restart the engine and drive vehicle up and off the grade. Repeat twice.

D. High Speed Gradeability - Ref: Performance Goal 13.0

Vehicle Load - 50,000 lb. GCW with towed trailer.

Requirement - Ascend not less than a 2% grade at 30 MPH at 50,000 lb. GCW.

Equipment Required - a) M-345 Pintle trailer, b) Calibrated fifth wheel.

Method - A stretch of public roadway must be identified with a 2% minimum sustained grade. The vehicle will approach the grade at a speed not to exceed 35 MPH and the minimum speed on the grade shall be recorded. Repeat twice.

E. Cruising Range - Ref: Performance Goal 21.0

Vehicle Load - 10,000 lb. payload plus towed load of 15,000 lbs including trailer.

Requirement - Operate for not less than 300 miles at an average speed of 30 MPH on hard surfaced road over an average (Michigan) rolling terrain, without refueling.

Equipment Required - Vehicle odometer

Method - Contractor may choose to perform this task during preliminary 1,000 miles of running by advance notice to TACOM. Fuel tank will be filled and sealed with wax seal. After completion of 300 miles with time recorded, seal will be broken and amount of fuel added to tank recorded. This test does not have to be repeated.

F. Cross Country Operation - Ref: Performance Goal 9.0

Vehicle Load - 10,000 lbs. payload plus towed load of 15,000 lbs.

Requirement - The vehicle shall transport rated cross country payload and towed load over unimproved roads, trails, open fields, hills and rough cross country terrain.

Equipment Required - M-345 trailer with load

Method - Accumulate 3 miles of various cross country conditions available at Eaton Proving Grounds.

G. Panic Braking

Vehicle Load - 10,000 lb. payload

Requirement - The vehicle must be braked without stalling the engine.

Equipment Required - None

Method - Apply brakes to maximum capacity at vehicle speeds ranging from 10 MPH to 40 MPH on various coefficient surfaces to assure that clutch disengages and does not stall engine. Repeat for eight combinations of speed and surface and record.

H. Shift Performance

Vehicle Loads - 33,000 lbs. GVW to 50,000 lbs. GCW

Requirements - Make oscillograph recordings of various shift conditions.

- a) Upshifts on 30% grade in off-road mode
- b) Forced downshifts on 30% grade in off-road mode
- c) 50,000 lb. GCW upshifts and downshifts in highway shift mode

This will be used to document shift time performance

Equipment Required - a) 10 channel oscillograph, b) M-345 trailer

Method - Establish desired test conditions and record shifts as required. Breakdown typical shift sequences for time of each element of shift sequence.

I. Clutch Protection Circuit

Vehicle Load - 35,000 lb. GVW

Requirements - Demonstrate that clutch protection circuit prevents clutch abuse by applying clutch fully if improper gear is selected for starting. This will either cause engine stall or wheel slippage depending on road surface and load conditions.

Equipment Required - 10 channel oscillograph

Method - (1) With vehicle loaded to 35,000 lbs., attempt start on 30% grade with transmission in 5th gear (drive position 'D' on selector lever). Repeat three times.

(2) By use of towing dynamometer or other loading device, evaluate ability to cause wheel slippage with various surface coefficients of traction under excessive starting conditions.

J. Acceleration Test

Vehicle Load - Base vehicle, 35,000 lb. GVW; 50,000 lb. GCW

Requirements - Determine the time vs. speed to 50 mph under each load condition on paved level roadway.

Equipment Required - (a) Calibrated fifth wheel; (b) 10-channel oscillograph; (c) M-345 trailer

VI. Government Furnished Support Equipment

A M-345 ten-ton, Pintle type trailer has already been delivered to Eaton Proving Grounds for use in this test plan.

VII. Extent of Contractor Participation

All of the tests shall be performed with contractor engineering and support personnel. The instrumentation will be provided by the contractor.

VIII. U.S. Army (TACOM) Participation

A representative of TACOM will witness the tests and sign the test sheets as tests are completed.

IX Instrumentation

The M-923 test truck has been fitted with a test kit for the AMT which allows monitoring of the transmission system during operation as well as providing override or limp home capability if a component malfunction should occur.

Attachment - Page 8

A 10 channel, Midwestern Instrument Oscillograph is installed in the vehicle. Typically the 10 channels record the following information:

1. Engine speed - RPM
2. Input speed - RPM
3. Output speed - RPM
4. Throttle pedal position
5. Clutch apply pressure - PSI
6. Synchronous speed error across jaw clutch - RPM
- 7, 8, and 9. Multiplexed logic signals from sensors
or to solenoids
10. Spare channel

Data will also be recorded with assistance of other devices such as fifth wheels, stopwatches, standard vehicle instrumentation as may be required.

X. Data Reduction and Analysis

Most of the tests outlined in this test plan are pass/fail in recording the results.

In those cases where oscillograph data is collected for shift performance for example, the data will be analyzed and broken into time elements manually.

All of the test results will be compiled in the final report for the contract.

RCH/ch

1/22/85

Revision: 4/10/85

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

A. High Speed - Ref: Performance Goal 12.0

Vehicle Load - 50,000 lbs GCW with towed load.

Requirement - Operate at a sustained high speed of not less than 50 MPH.

Equipment Required - a) M-345 Pintle Trailer, b) Calibrated fifth wheel for accurate speed measurement.

Method - Record minimum and maximum speeds over each of five laps (8 miles total) of proving ground's oval track, after transmission is in high gear (16th). Repeat twice.

Test Results:

$$\text{GCW} = \frac{10,300}{(1)} + \frac{24,730}{(1)} + \frac{15,120}{(2)} = \frac{50,150}{(2)} \text{ lbs.}$$

Lap	Speed	Speed
	Min/Max	Min/Max
1	41.7/55.4	42.8/57.1
2	50.7/58.3	51.7/58.7
3	50.7/58.7	52.2/58.3
4	51.7/58.7	51.9/58.7
5	51.7/58.7	51.9/58.7
6		
7		
8		

Comments:

B-10

	Signature	Date
Eaton Witness:	<u>E. James Lane</u>	<u>4/17/85</u>
TACOM Witness:	<u>Robert J. Rudmating</u>	<u>4-17-85</u>

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

B. Low Speed - Ref: Performance Goal 13.0

Vehicle Load - Not specified

Requirement - Operate at a sustained low speed of not more than 2-1/2 MPH without damage to the vehicle.

Equipment Required - Calibrated fifth wheel

Method - Record ambient temperature and engine water and transmission oil temperatures as test run is started. Drive in low gear (1st) for 2 miles (48 minutes) and record the engine water and transmission oil temperatures every 10 minutes until completion of test. Repeat twice.

Test Results:

GVW = 34960 + 14320 = 49,280 lbs.

1) Ambient Temperature = 50 °F

	Start	1	2	3	4	Final
Time	0	10m	20	30	40	48 MINUTES
Engine Coolant °F	182°F	180°F	180	180	180	180°F
Trans. Oil °F	125°F	110°F	110	110	110	110°F

2) Ambient Temperature = _____ °F

	Start	1	2	3	4	Final
Time	NOTE 2ND REPEAT DEFERRED					
Engine Coolant °F	UNTIL A WARMER AMBIENT					
Trans. Oil °F	TEMP. IS AVAILABLE					

Comments:

1350 - 1450 RPM
ENGINE SPEEDS

B-11

	Signature	Date
Eaton Witness:	<u>[Signature]</u>	<u>MARCH 19, 1985</u>
TACOM Witness:	<u>[Signature]</u>	<u>19 MARCH 1985</u>

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

B. Low Speed - Ref: Performance Goal 13.0

Vehicle Load - Not specified

Requirement - Operate at a sustained low speed of not more than 2-1/2 MPH without damage to the vehicle.

Equipment Required - Calibrated fifth wheel

Method - Record ambient temperature and engine water and transmission oil temperatures as test run is started. Drive in low gear (1st) for 2 miles (48 minutes) and record the engine water and transmission oil temperatures every 10 minutes until completion of test. Repeat twice.

Test Results:

RUN 2

GVW = 10,875 + 22,450 = 33,325 lbs.

1) Ambient Temperature = 63 °F

	Start	1	2	3	4	Final
Time	0	10	20	30	40	48 min
Engine Coolant °F	125°F	165°F	170°F	175°F	175°F	175°F
Trans. Oil °F	150°F	120°F	120°F	120°F	120°F	120°F

2) Ambient Temperature = _____ °F

	Start	1	2	3	4	Final
Time						
Engine Coolant °F						
Trans. Oil °F						

Comments:

B -12

	Signature	Date
Eaton Witness:	<u>E. J. [Signature]</u>	<u>4/17/85</u>
TACOM Witness:	<u>Ronan J. [Signature]</u>	<u>4-17-85</u>

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

C. Gradeability on 60% Slope - Ref: Performance Goal 18.0

Vehicle Load - 10,000 lb. payload

Requirement - Negotiate a 60% grade at a minimum speed of 2-1/2 MPH.

The grade surface shall be smooth dry concrete.

Equipment Required - Instrumentation package to verify engine speed for vehicle speed calculation.

Method - The 60% grade will be negotiated twice. On the second time, the vehicle shall be stopped and the engine shutdown. After two minutes, restart the engine and drive vehicle up and off the grade. Repeat twice.

Test Results:

GVW = 10,875 + 22,450 = 33,325 lbs.

Pass/Fail

- 1) Climb 60% Grade
- 2) Stop and Restart on 60% grade
- 3) Repeat 1
- 4) Repeat 2

Comments:

CHART #1 1ST CLIMB OF 60% GRADE
CHART #2 2ND CLIMB OF 60% GRADE
CHART #3 1ST STOP & RESTART ON 60% GRADE
(REAR DRIVE ONLY)
CHART #4 2ND STOP & RESTART ON 60% GRADE
(ALL WHEEL DRIVE)

B-13

	Signature	Date
Eaton Witness:	<u>E. James Lane</u>	<u>4/16/85</u>
TACOM Witness:	<u>L. J. Rudmisy</u>	<u>4-16-1985</u>

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

D. High Speed Gradeability - Ref: Performance Goal 13.0

Vehicle Load - 50,000 lb. GCW with towed trailer.

Requirement - Ascend not less than 2% grade at 30 MPH at 50,000 lb. GCW.

Equipment Required - a) M-345 Pintle trailer, b) Calibrated fifth wheel.

Method - A stretch of public roadway must be identified with a 2% minimum sustained grade. The vehicle will approach the grade at a speed not to exceed 35 MPH and the minimum speed on the grade shall be recorded. Repeat twice.

Test Results:

1) GCW = 10,300 + 24,730 + 15,120 = 50,150 lbs.

2) Route Description:

US ROUTE 131 SOUTH FROM D AVENUE SIGN POST
TO JUST NORTH OF MILE MARKER 44 1 1/8 MILES
GRADE IS 3%. INFORMATION RECEIVED FROM
CLYDE MAYLATH STATE OF MICHIGAN HIGHWAY
DEPARTMENT (616) 327-3054

3) Speed on Grade: (1) Min/Max (2) Min/Max

Comments:

1ST RUN START 33.6 MPH 28 MPH MIN/38 MPH MAX
2ND RUN START 32.1 MPH 26 MPH MIN/37.2 MPH MAX

B-14

	Signature	Date
Eaton Witness:	<u>E. J. [Signature]</u>	<u>4/17/85</u>
TACOM Witness:	<u>Roman J. Rudrityay</u>	<u>4-17-85</u>

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121
Data Sheet

E. Cruising Range - Ref: Performance Goal 21.0

Vehicle Load - 10,000 lb. payload plus towed load of 15,000 lbs.
including trailer.

Requirement - Operate for not less than 300 miles at an average speed
of 30 MPH on hard surfaced road over an average (Michigan) rolling
terrain, without refueling.

Equipment Required - Vehicle odometer

Method - Contractor may choose to perform this task during preliminary
1,000 miles of running by advance notice to TACOM. Fuel tank will be
filled and sealed with wax seal. After completion of 300 miles with
time recorded, seal will be broken and amount of fuel added to tank
recorded. This test does not have to be repeated.

Test Results:

Miles completed = 310.2 miles
Travel time = 10h 39min hours
Average speed = 28.8 MPH (calculated)
Fuel consumed = 49.2 gallons
Fuel consumption = 6.3 MPG (calculated)

START HUB ODOMETER 4775.4
TANK SEALED

Final Hub ODOMETER 5085.6

Comments:

ROUTE 4/17 70.3 miles on MPG track
4/18 MPG to west I94 to North I69 to
East I96 to North US23 to North I75
to South I475 (Ellet) to North I69 to
East M21 to South M53 to West M59 to
South I75 to West Square Lake Rd to
South Telegraph Road to West Lash Rd to ELL

TIME 4/17 2h 9 min
4/18 2h 30 min; 3h 30 min; 2h 30 min

Eaton Witness:

TACOM Witness:

Signature

Date

[Signature]
[Signature]

4-1985
4-1985

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

F. Cross Country Operation - Ref: Performance Goal 9.0

Vehicle Load - 10,000 lbs. payload plus towed load of 15,000 lbs.

Requirement - The vehicle shall transport rated cross country payload and towed load over unimproved roads, trails, open fields, hills and rough cross country terrain.

Equipment Required - M-345 trailer with load

Method - Accumulate 3 miles of various cross country conditions available at Eaton Proving Grounds

Test Results:

Course Description:

COURSE CONSISTED OF SECONDARY (GRAVEL) ROADS AND UNIMPROVED CROSS COUNTRY TRAILS WITH BOTH FLAT AND ROLLING TERRAIN - GROUND CONDITIONS WERE SOFT TO MUDY (SPRINKLE THAW). COURSE LENGTH = 3.4 MILES

Comments:

GCW = 10340 FRONT + 24620 TANDEN + 14310 TRAILER

GCW = 49280 LBS

AMBIENT TEMP = 50°F

B-16

	Signature	Date
Eaton Witness:	<u>Russell C. Helms</u>	<u>MARCH 19, 1985</u>
TACOM Witness:	<u>Roman J. Rudmity</u>	<u>19 March 1985</u>

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION

Re: Contract DAAE07-82-C-4121

Data Sheet

G. Panic Braking

Vehicle Load - 10,000 lb. payload

Requirement - The vehicle must be braked without stalling the engine.

Equipment Required - None

Method - Apply brakes to maximum capacity at vehicle speeds ranging from 10 MPH to 40 MPH on various coefficient surfaces to assure that clutch disengages and does not stall engine. Repeat for eight combinations of speed and surface and record.

Test Results

$$GVW = 10865 + 22730 = 33595 \text{ lbs.}$$

Test	MPH	Road Surface	Result
1	20	GRAVEL	ENGINE RUNNING
2	30	GRAVEL	" "
3	10	HIGH μ (-8 to -85)	" "
4	20	HIGH μ	" "
5	30	HIGH μ	" "
6	20	WET GENIE (-3 to 3)	STALLED
7	30	WET GENIE	ENGINE RUNNING
8	40	WET GENIE	" "
9	30	WET GENIE	" "

Comments:

NOTE: ON RUN 7 (30 MPH AND $\mu = -3$) ENGINE STALLED
DRIVER SAID HE WAS STILL ACCELERATING AND
DEPRESSED BRAKE PEDAL WITH LEFT FOOT.
HE MAY NOT OF REMOVED RIGHT FOOT FROM
THROTTLE PEDAL QUICK ENOUGH

Signature _____ Date _____
Eaton Witness: Roman C. [Signature] March 19, 1985
TACOM Witness: Roman J. Rudnitsky 19 March 1985

BEST AVAILABLE COPY

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

H. Shift Performance

Vehicle Loads - 33,000 lbs. GVW to 50,000 lbs. GCW

Requirements - Make oscillograph recordings of various shift conditions.

- a) Upshifts on 30% grade in off-road mode
- b) Forced downshifts on 30% grade in off-road mode
- c) 50,000 lb. GCW upshifts and downshifts in highway shift mode

This will be used to document shift time performance

Equipment Required - a) 10 channel oscillograph, b) M-345 trailer

Method - Establish desired test conditions and record shifts as required. Breakdown typical shift sequences for time of each element of shift sequence.

Test Results:

CONDITIONS a) & b)

GVW/GCW = _____ + _____ = 33,325 lbs.

Test Condition:

CLEAR & DRY 66°F

Strip Chart Identification No. 5 11-3 DOWNSHIFT FOLLOWED

Comments:

BY 3-4 UPSHIFT ON
30% GRAVEL GRADE

CHART #6 3-4 & 4-5 UPSHIFTS
ON 30% GRAVEL GRADE

UP & DOWNSHIFTING OVER VARIOUS CROSS
COUNTRY TERRAIN. RANGING FROM HARD & DRY
TO MUDDY.

	Signature	Date
Eaton Witness:	<u>E. James Lane</u>	<u>4/16/85</u>
TACOM Witness:	<u>Roman J. Redmire</u>	<u>4/16-85</u>

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

H. Shift Performance

Vehicle Loads - 33,000 lbs. GVW to 50,000 lbs. GCW

Requirements - Make oscillograph recordings of various shift conditions.

- a) Upshifts on 30% grade in off-road mode
- b) Forced downshifts on 30% grade in off-road mode
- c) 50,000 lb. GCW upshifts and downshifts in highway shift mode

This will be used to document shift time performance

Equipment Required - a) 10 channel oscillograph, b) M-345 trailer

Method - Establish desired test conditions and record shifts as required. Breakdown typical shift sequences for time of each element of shift sequence.

Test Results:

CONDITION C)

$$\begin{aligned} \text{GVW/GCW} &= \underline{10,210} + \underline{24,550} + \underline{14,430} = \underline{49,190} \\ &= \underline{10,300} + \underline{24,730} + \underline{15,120} = \underline{50,150} \end{aligned}$$

ADDED 1000 LBS TO TRAILER

Test Condition:

CLEAR & DRY 66°F
LIGHT WIND

Strip Chart Identification No. 7 NOT UPSHIFTS 5-15

Comments: USING SKID PAD (TRAILER WAS CLOSED) INSUFFICIENT ROOM TO MAKE 16 TH.

CHART # 8 NOT UPSHIFTS 5-15 FOLLOWED BY LIGHT BRAKING DOWNSHIFTS 15-5.

CHART # 9 1/2 THROTTLE UPSHIFTS 5-16

	Signature	Date
Eaton Witness:	<u>[Signature]</u>	<u>4/16/85</u>
TACOM Witness:	<u>[Signature]</u>	<u>4-16-85</u>

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

J. Acceleration Test

Vehicle Load - Base vehicle, 35,000 lb. GVW; 70,000 lb. GCW

Requirements - Determine the time vs. speed to 50 mph under each load condition on paved level roadway.

Equipment Required - (a) Calibrated fifth wheel; (b) 10-channel oscillograph; (c) M-345 trailer

Test Results:

GCW/GVW = 10,155 + 11,775 = 21,930 lbs.

Fifth Wheel Serial Number = 1459 TRACKTEST BY LABECO

Ambient Temperature 63°F

Test	Time	Chart (Y/N)
1	37.33	CHART # 11
2	35.76	NO
3	34.19	NO

AVE 35.76 SEC

Course Description:

EATON PROVING GROUNDS 1.6 MILES OVAL TRACK
START AT BASE OF GRADE AND REACH 50MPH
ON EAST STRAIGHT

Comments:

	Signature	Date
Eaton Witness	<u>E. James Lane</u>	<u>4/17/85</u>
TACOM Witness	<u>Roman J. Gudimov</u>	<u>4-17-85</u>

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

J. Acceleration Test

Vehicle Load - Base vehicle, 35,000 lb. GVW; 70,000 lb. GCW

Requirements - Determine the time vs. speed to 50 mph under each load condition on paved level roadway.

Equipment Required - (a) Calibrated fifth wheel; (b) 10-channel oscillograph; (c) M-345 trailer

Test Results:

~~GVW~~/GVW = $10865 + 22730 = 33595$ lbs.

Fifth Wheel Serial Number = 1459 TRACKTEST 6, LABELED

Ambient Temperature = 60°F

STARTING GEAR
Test Time Chart (Y/N)

1	3	57.63 sec	N
2	3	55.48 sec	N
3	3	54.11 sec	N

Ave Time = 56.125

Course Description:

EATEN PROVING GROUNDS 1.6 MILE ORAL
START AT BASE OF GRADES AND REACH
50MPH IN MIDDLE OF TARD

Comments:

HEAVY CROSS-WIND TENDING TO HEADWIND
AS 50MPH APPROACHED - WIND VELOCITY
ESTIMATED AT 15 TO 20 MPH

	Signature	Date
Eaton Witness	<u>Roman J. Preliminary</u>	<u>MARCH 19, 1985</u>
TACOM Witness	<u>Roman J. Preliminary</u>	<u>19 March 1985</u>

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

J. Acceleration Test

Vehicle Load - Base vehicle, 35,000 lb. GVW; 70,000 lb. GCW

Requirements - Determine the time vs. speed to 50 mph under each load condition on paved level roadway.

Equipment Required - (a) Calibrated fifth wheel; (b) 10-channel oscillograph; (c) M-345 trailer

Test Results:

GCW/GVW = 10865 + 22730 = 33595 lbs.

Fifth Wheel Serial Number = 1459 LABELED

Ambient Temperature = 60°F

STARTING GEAR =

Test		Time	Chart (Y/N)
------	--	------	-------------

1	5	54.28	
---	---	-------	--

2	5	53.89	
---	---	-------	--

3	5	54.42	
---	---	-------	--

AVE TIME = 54.20

Course Description:

Eaton Proving Grounds 1.6 MILE OVAL TRACK
START AT BASE OF GRADES AND REACH 50MPH
IN MIDDLE OF NORTH TURN

Comments:

HEAVY CROSS-WIND TURNING TO HEAD WIND
AS 50 MPH IS APPROACHED IN TURN-
WIND VELOCITY IS ESTIMATED AT 15 TO
20 MPH

Eaton Witness

Signature

Date

TACOM Witness

Russell D. Helman MARCH 19, 1985
Roman J. Rudmity 19 March 1985

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

J. Acceleration Test

Vehicle Load - Base vehicle, 35,000 lb. GVW; ^{50,000}~~35,000~~ lb. GCW

Requirements - Determine the time vs. speed to 50 mph under each load condition on paved level roadway.

Equipment Required - (a) Calibrated fifth wheel; (b) 10-channel oscillograph; (c) M-345 trailer

Test Results:

GCW/GVW = 10,300 + 24,730 = 35,120 ~~lbs.~~ = 50,150 lbs

Fifth Wheel Serial Number = 1459 TRACKTEST BY LABECO

Ambient Temperature 54°F

Test	Time	Chart (Y/N)
1	1:47.21	CHART #10
2	1:37.57	NO
3	1:32.23	NO

Course Description:

EATON PROVING GROUND S 1/6 MILE OVAL TRACK
START ON WEST STRAIGHT REACH 50 MPH
START OF WEST STRAIGHT

Comments:

151
47
7
3/29/85
98

Signature
Eaton Witness E. James Lane
TACOM Witness Roman J. Redington

Date
4/17/85
4/17/85

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

C. Gradeability on 60K% Slope - Ref: Performance Goal 18.0

Vehicle Load - 10,000 lb. payload

Requirement - Negotiate a 60% grade at a minimum speed of 2-1/2 MPH.

The grade surface shall be smooth dry concrete.

Equipment Required - Instrumentation package to verify engine speed for vehicle speed calculation.

Method - The 60% grade will be negotiated twice. On the second time, the vehicle shall be stopped and the engine shutdown. After two minutes, restart the engine and drive vehicle up and off the grade. Repeat twice.

Test Results:

GVW = 12,450 + 20,030 = 32,480 lbs.

	Pass/Fail
1) Climb 60% Grade	PASS
2) Stop and Restart on 60% grade	PASS
3) Repeat 1	PASS
4) Repeat 2	PASS

Comments:

FRONT DRIVE SHAFT NOT INSTALLED.

	Signature	Date
Eaton Witness:	<u>Ron Markewich</u>	<u>6-10-86</u>
TACOM Witness:	<u></u>	<u></u>

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION

Re: Contract DAAE07-82-C-4121

Data Sheet

G. Panic Braking

Vehicle Load - 10,000 lb. payload

Requirement - The vehicle must be braked without stalling the engine.

Equipment Required - None

Method - Apply brakes to maximum capacity at vehicle speeds ranging from 10 MPH to 40 MPH on various coefficient surfaces to assure that clutch disengages and does not stall engine. Repeat for eight combinations of speed and surface and record.

Test Results

$$GVW = \underline{12,450} + \underline{20,030} = \underline{32,480} \text{ lbs.}$$

Test	MPH	Road Surface	Result
1	10	M • 3	did not stall
2	20	" • 3	did not stall
3	30	" • 3	did not stall
4	40	" • 3	stalled
5			
6			
7			
8			

Comments:

Signature

Date

Eaton Witness: P. J. [Signature]

6-10-86

TACOM Witness: _____

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

J. Acceleration Test

Vehicle Load - Base vehicle, 35,000 lb. GVW; 70,000 lb. GCW

Requirements - Determine the time vs. speed to 50 mph under each load condition on paved level roadway.

Equipment Required - (a) Calibrated fifth wheel; (b) 10-channel oscillograph; (c) M-345 trailer

Test Results:

GCW/GVW = 12,450 + 20,030 = 32,480 lbs.

Fifth Wheel Serial Number = _____

Ambient Temperature 71°F

Test STARTING Gear

Time Chart (Y/N)

1 5TH 52.6 sec N

2 3RD 41.6 sec

3 5TH
52.6 sec

Course Description:

Comments:

Signature

Date

Eaton Witness _____

6-9-86

TACOM Witness _____

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

J. Acceleration Test

Vehicle Load - Base vehicle, 35,000 lb. GVW; 70,000 lb. GCW

Requirements - Determine the time vs. speed to 50 mph under each load condition on paved level roadway.

Equipment Required - (a) Calibrated fifth wheel; (b) 10-channel oscillograph; (c) M-345 trailer

Test Results:

GCW/GVW = $12,450 + 20,030 = 32,480$ lbs.

Fifth Wheel Serial Number = _____

Ambient Temperature 73°F

Test		Time	Chart (Y/N)
1	5TH START THEN 3RD	47.1 sec	NO
2	"	45.7 sec	NO
3	"	44.1 sec	NO

Course Description:

EATON PROOING GROUNDS 1.6 mile OVAL TRACK
STARTS AT THE BASE OF GRADES AND RACE
SOUTH IN MIDDLE OF NORTH TURN.

Comments:

5TH WHEEL NOT WORKING SO THE SOUTH WAS
READ FROM THE VEHICLE SPEEDOMETER.

	Signature	Date
Eaton Witness	<u>Re. M. [Signature]</u>	<u>6-9-86</u>
TACOM Witness	_____	_____

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

J. Acceleration Test

Vehicle Load - Base vehicle, 35,000 lb. GVW; 70,000 lb. GCW

Requirements - Determine the time vs. speed to 50 mph under each load condition on paved level roadway.

Equipment Required - (a) Calibrated fifth wheel; (b) 10-channel oscillograph; (c) M-345 trailer

Test Results:

GCW/GVW = 12,450 + 20,030 = 32,480 lbs.

Fifth Wheel Serial Number = _____

Ambient Temperature 73 °F

Test	Time	Chart (Y/N)
1 5TH WHEEL	50.8 sec	NO
2	50.1 sec	NO
3	51.0 sec *	NO

Course Description:

Eaton PROUDLY grounds 1.6 mi OVAL TRACK
STARTS AT THE BASE OF THE GRADES AND
REACHS 50 MPH IN THE MIDDLE OF THE NORTH TURN.

Comments:

* 3rd trial RECORDED 13TH GEAR

5TH wheel not working so 50 mph WAS READ
FROM THE vehicle SPEEDOMETER.

	Signature	Date
Eaton Witness	<u>Ramondy</u>	<u>6-9-86</u>
TACOM Witness	_____	_____

TEST PLAN FOR AUTOMATED MECHANICAL TRANSMISSION
Re: Contract DAAE07-82-C-4121

Data Sheet

J. Acceleration Test

Vehicle Load - Base vehicle, 35,000 lb. GVW; 70,000 lb. GCW

Requirements - Determine the time vs. speed to 50 mph under each load condition on paved level roadway.

Equipment Required - (a) Calibrated fifth wheel; (b) 10-channel oscillograph; (c) M-345 trailer

Test Results:

GCW/GVW = 12,450 + 20,030 = 32,480 lbs.

Fifth Wheel Serial Number = _____

Ambient Temperature 73°F

Test	Start	Genl Time	Chart (Y/N)
1	1st	50.7 sec	NO
2	"	50.3 sec	NO
3	"	50.2 sec	NO

Course Description:

EATON PROVING GROUNDS DUAL TEST TRACK
START AT THE POINT OF THE CURVES AND RACE
50 MPH TO THE POINT OF THE TURN.

Comments:

5th wheel not working so 50 MPH WAS READ FROM
THE VEHICLE SPEEDOMETER.

Signature

Date

Eaton Witness

Ron M. [Signature]

6-9-86

TACOM Witness

APPENDIX C

PROCESSING ANALYSIS OF
COUNTERSHAFT GEAR PN 56453

Date: August 14, 1997⁸⁶

Project No. 4097-03

To: W. R. Pankratz

Copy: B. Lisowsky

From: D. Vukovich

Subject: **PROCESSING ANALYSIS OF COUNTERSHAFT GEAR PN 56453**

Conclusions

1. The pitch line case depth does not meet minimum print requirements.
2. Root case depth and core hardness are at the minimum required by the print.
3. The sample cracked as a result of low to minimum case depth and core hardness.
4. The gear chemistry is within the range specified for 8620H steel.

Recommendation

Check the residual stress in the roots of gear teeth after assembly (welding) and after testing, prior to removal from the shaft.

Reference

Material hardness specification TES-003.

Sample Selection and Test Procedure

One cracked countershaft gear PN 56453 was submitted for routine hardness and microstructural evaluation. Case depth and hardness were measured and a sample was sent to Chicago Spectrographic for chemical analysis. Residual stress measurements were not taken because the gear was cut from the shaft, altering the residual stress state.

Chemical Analysis

ELEMENT	SAMPLE	8620H SPEC.
C	.20	.017/.023
Mn	.79	.060/.095
P	.008	.025 Max.
S	.019	.025 Max.
Si	.25	.015/.035
Ni	.47	.035/.075
Cr	.56	.035/.065
Mo	.17	.015/.025
Cu	.14	--
Al	.024	

Page Two
W. R. Pankratz
August 14, 1986

Discussion

The countershaft gear (Figure 1A) showed evidence of cracking (Figure 1B) in nine tooth roots. A typical root core microstructure contains tempered martensite and retained austenite. Similar case and core structures were found at the pitch diameter with the exception that the finer lath martensite structure is present due to a higher cooling rate during quenching. Evidence of darker etching at the tips of the tooth cross section (not shown) indicates that the tooth tips were tempered (overheated) during testing. The overheating explains the observation that the root case is at the minimum specified depth while the pitchline case is less than specified.

Summary

Table I shows that pitch diameter effective case depth does not meet the .023 inch print specification. All other readings just meet minimum print requirements.

The sample cracked as the result of low to minimum case depth and core hardness.



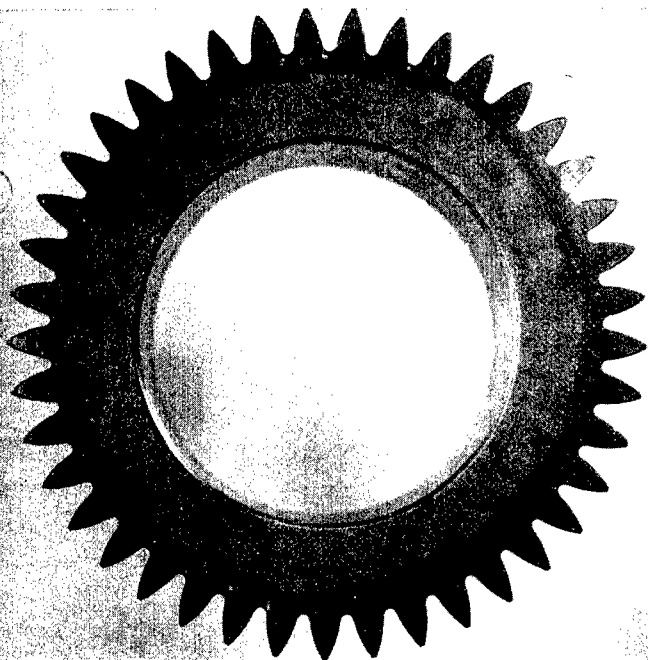
DTV/i
Att.

TABLE I. PROCESSING DATA SUMMARY COUNTERSHAFT
GEAR 56453

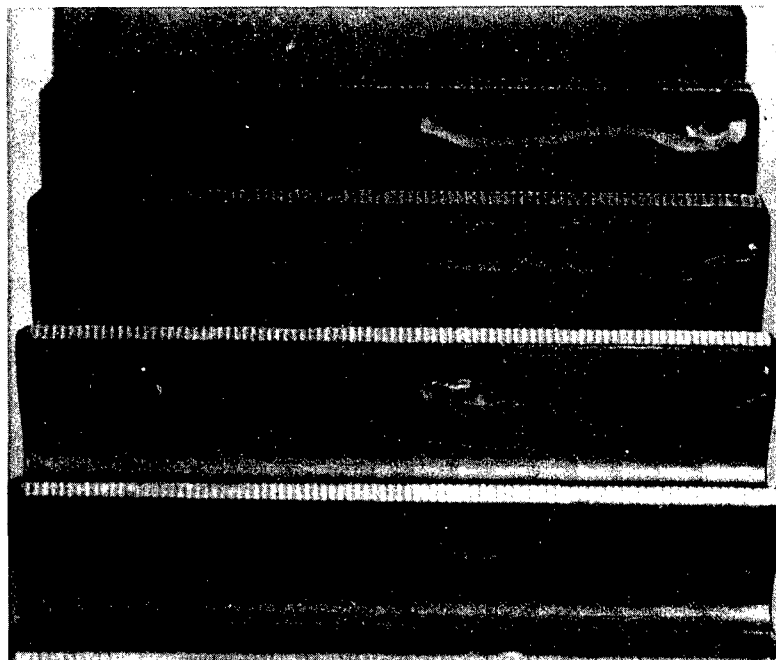
PART NO.	SURFACE HARDNESS HRA	EFFECTIVE CASE DEPTH INCH (2)		CORE HARDNESS, HRC		FRACTURE MODE
		PITCH DIA.	ROOT(1)	PITCH DIA.	ROOT	
Spec. 56453	80-83	.023/.033	.016/.023	30-42	25-37	
Gear 56453	81-82	.020	.016	30	26	Root cracks

(1) Not less than 70% of the minimum pitch line case per TS-003

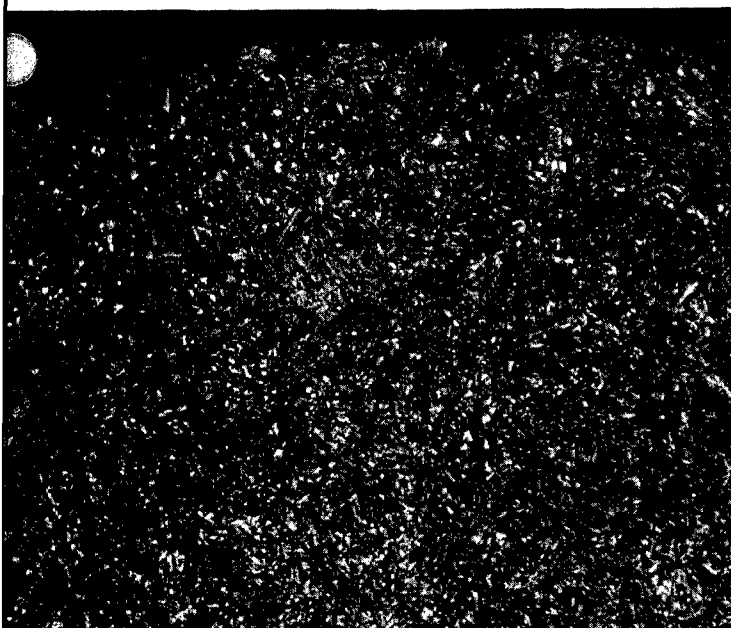
(2) Depth to HRC 50



A. COUNTERSHAFT GEAR (56453) SHOWING LOCATION OF CRACKED TEETH



B. GEAR TEETH SHOWING LOCATION OF CRACKS



C. ROOT CASE MICROSTRUCTURE: PLATE MARTENSITE AND RETAINED AUSTENITE, HRC 59, 500X



D. ROOT CORE MICROSTRUCTURE: LATH MARTENSITE, HRC 26, 500X

FIGURE 1. COUNTERSHAFT GEAR (56453) SHOWING CRACKED TEETH, ROOT CASE AND CORE MICROSTRUCTURE.

APPENDIX D

DROP BOX GEARS - SURFACE RESIDUAL STRESS

Date: August 12, 1986
To: W. Pankratz
Copy: B. Lisowsky
From: A. Ahmad
Subject: DROP BOX GEARS - SURFACE RESIDUAL STRESS

P/N 4097-03

Residual stress evaluation was made on three transmission gears. The gears from TACOM (16 speed) are identified below:

1. Gear Mainshaft Output
2. Gear Idler
3. Gear Output Drive Rear

These have already seen approximately 12,000 miles.

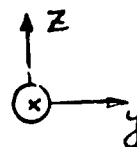
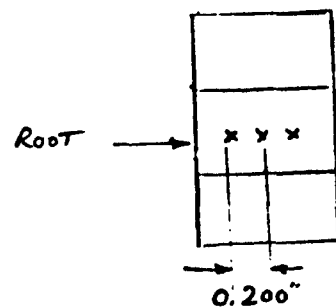
Three residual stress measurements were taken on each root, 0.200 inch apart in the center of the gear as shown in sketch. Three roots, 120° apart on each gear were measured for residual stress.

From the surface residual stress values, it is seen that the gears were subjected to shot cleaning/peening process. The compressive residual stress ranges from 55 ksi to 83 ksi.



AA/i
Att.

Orientation and Location of
Surface R.S.



Part #	Root #	Av. Surface R.S. KSI
56776D ✓	1	-61
	2	-61
	3	-55
56833D	1	-62
	2	-72
	3	-57
56839E	1	-83
	2	-75
	3	-83

A.A.
7-29-86

APPENDIX E

DROP BOX GEARS – RESIDUAL STRESS

Date: September 11, 1987

P/N: 3815-03

To: W. Pankratz -- Engineering & Research Center

Copy: B. Lisowsky

From: A. Ahmad -- Engineering & Research Center

Subject: DROP BOX GEARS -- RESIDUAL STRESS

At your request, a gear identified as 56776-D was subjected to surface and sub-surface residual stress (R.S.) for the verification of processing.

Earlier in August 1986, surface R.S. measurements were performed on 3 gears. At that time sub-surface measurements were not conducted, since further testing of these 16-speed gears was expected. A copy of the memo is attached.

The residual stress depth profile obtained on gear 56776-D indicates the gear was properly shot peened. The surface, as well as sub-surface R.S., particularly at 0.001 inch depth is high compressive.

The results obtained on the root are as follows:

Surface	- 59 ksi
Sub-surface (0.0015 inch)	-104 ksi
Sub-surface (0.005 inch)	- 44 ksi

Measurements were taken at the bottom of the root at mid-width of the gear. Sub-surface readings were obtained after removal of the surface layer electrolytically (electro-chemical machining). The depth of layer removal was determined using a profilometer for root profile (Fig. 2), as well as replicating the root with a molding compound and measuring the dimensional change using shadowgraph.

Standard calibration procedure for transmission gear was followed.

Ahmad Ahmad

AA/ch

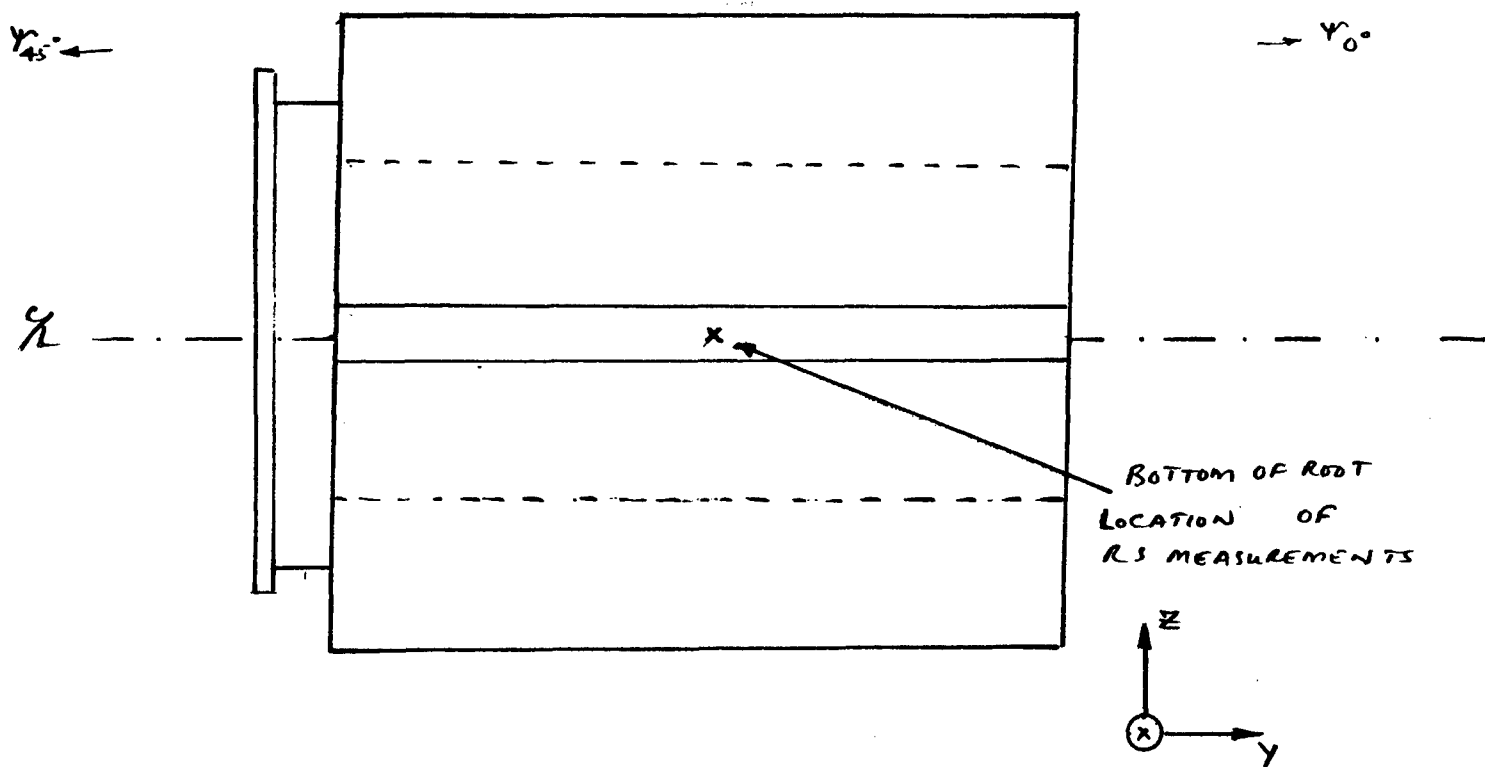
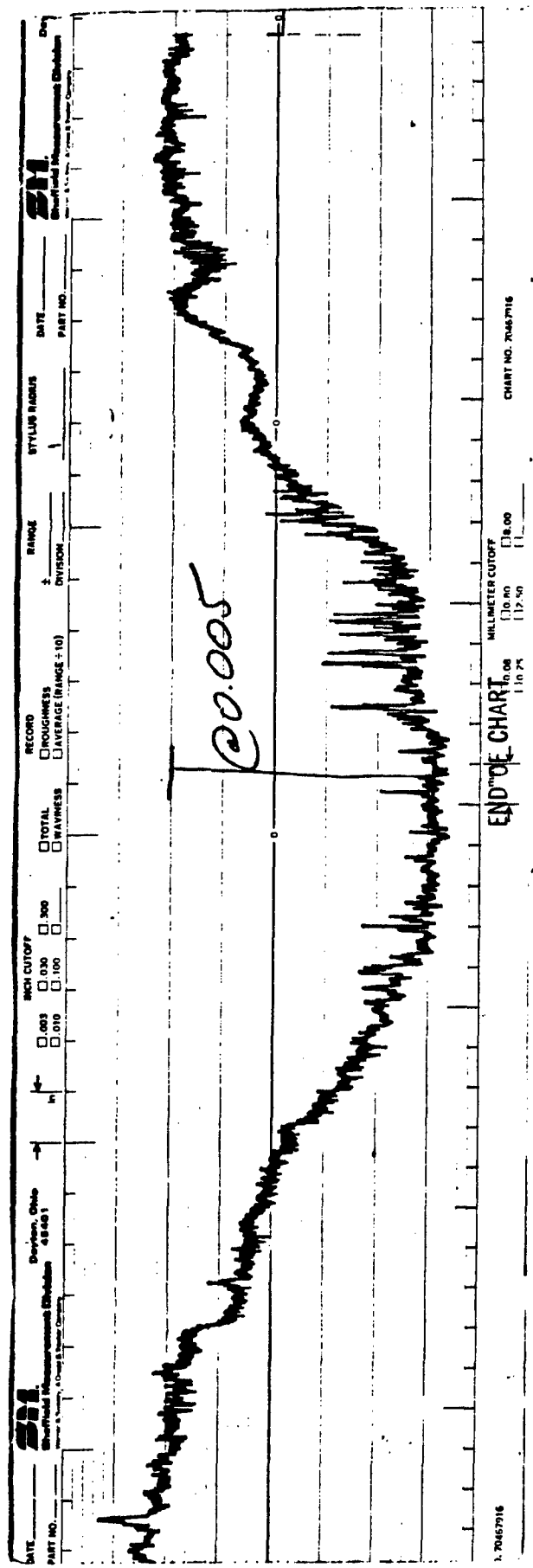
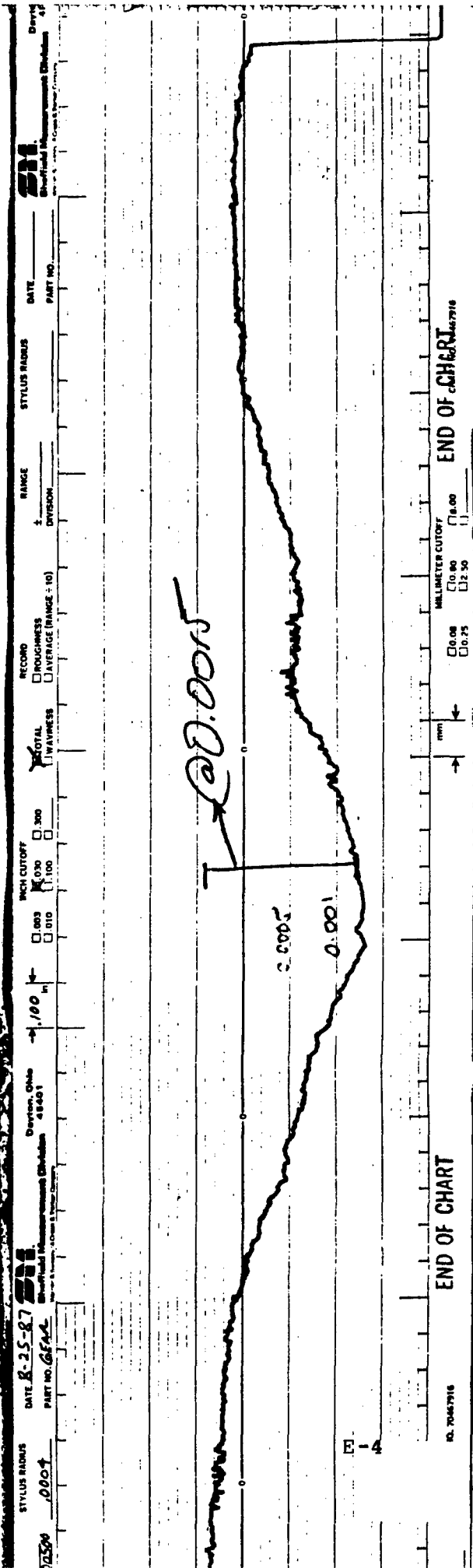


FIG. 1 - LOCATION AND ORIENTATION OF RS MEASUREMENTS .

FIG. 2

Spec # 58776-D 70385-03 6027142



APPENDIX F

INSPECTION REPORT ON AUSCO'S BRAKE

TO WILLIAM PANKRATZ
PROJECT ENGINEER
EATEN CORPORATION
ENGINEERING & RESEARCH CENTER
26201 NORTHWESTERN HIGHWAY
P.O. Box 766
SOUTHFIELD, MI 48037

FROM GEORGE DIERR
AUTO SPECIALTIES MANUFACTURING CO.
643 GRAVES STREET
ST. JOSEPH, MICH. 49085
926 0700
(616) 982-2211

SUBJECT INSPECTION REPORT

DATE 9/3/86

MESSAGE

ENCLOSED IS A COPY OF BOB KIBLER'S INSPECTION
REPORT ON THE RETURNED BRAKE PARTS TESTED ON
YOUR VEHICLE.
WE ARE PREPARING ORDERS FOR NEW MIDDLE DISCS AND A
NEW SPLINE ADAPTER TO BE MADE WITHIN THE 8 WEEK
TIME FRAME WE DISCUSSED TODAY ON THE PHONE.

SIGNED

George Dierr.

REPLY

CC. DON BROADBENT

SIGNED

DATE

SEND PARTS 1 AND 3 WITH CARBON INTACT - PART 3 WILL BE RETURNED WITH REPLY.

INSPECTION REPORT

OBJECT:

To report "after testing" dimensions of the components of an 11 x 8 inch multiple disc ball energizing brake, Assembly No. 36525.

PROCEDURE:

Parts were subjected to a "field test" by Eaton. After the test, all the parts appeared in good condition with exception of the splines within the middle disc assemblies and on the spline adapter. The splines were severely worn away in both parts.

Enclosed data sheets show specific dimensions taken from each part of the assembly. All the dimensions are within drawing tolerances after testing, except for the splines and a segment of lining which fell away from the core plate.

CONCLUSIONS:

The splines of the middle disc assemblies will be hardened to increase the wear capability.

The splines of the spline adapter will be hardened to increase the wear capability.

The "spalled" lining is not a serious problem. A small percentage (2%) of production discs may experience some lining spalling due to a weak interface structure at some localized areas of the surface of the disc. The amount of lining which "spalls" or "falls" off the disc will not affect the performance of the brake.

New middle disc assemblies, and a new spline adapter, will be made with hardened splines. The remainder of the parts can continue to be used for vehicle testing.

8/7/bas

F-3

8-7-86
RLK/BLER

Kg 1012

DATA SHEET - ENGINEERING SAMPLE

PROJECT NO. _____

ASSEMBLY NO. 36525T&D JOB NO. 14253DATE TESTED: 7-31-86CUSTOMER: CATON

P&SO: _____

SERIAL NO. _____

TECHNICIAN Ray Feltner

SHIPPER NO. _____

TEST DATA - COMMENTS:

11" X 8" DD Brake* Two intermediate DiscP/N 29972#1 measured @ center

Thickness	A	B	C
	.264"	.2645"	.2635"

Flatness #1 .019"Parallism .001"* #2

	A	B	C
--	---	---	---

Thickness

	.268"	.2685"	.2675"
--	-------	--------	--------

Flatness .0165"Parallism .001"* Middle Disc Assy.P/N MA 11750(36808)Thickness IN 6 places Comments: _____marked (C) #1 - .490 .489 (X) .490 .492 .491 Living chipped off (X) 1.5" x 1.5" on side11 (D) #2 - .493 .493 .492 .4915 .491 .492 Linings uneven at O.D. edge, when molded11 (A) #3 - .488 .488 .4885 .489 .489 .4885 Slight pitting, Both Faces.11 (B) #4 - .489 .488 .490 .490 .4885 .489 Slight pitting, Both Faces.P/N 36804* Actuator going CCW. @ Center of Ballramps, Starting at Link.

Thickness _____

1.9355"	1.934"	1.9325"	1.9365"
---------	--------	---------	---------

Flatness .0105"Parallism .004"Actuator has Slight Blueness color on one side. O.D. DIA.APX. 1" from O.D. INWARD. GRIND MARK still visible from center to I.D.2nd SIDE Slight Discoloration at center. Completely AROUND DIA.

242

DATA SHEET - ENGINEERING SAMPLE

PROJECT NO. _____

ASSEMBLY NO. _____

T&D JOB NO. 14253DATE TESTED: 8-5-86CUSTOMER: CALOW

P&SO: _____

SERIAL NO. _____

TECHNICIAN Bill Vaphely

SHIPPER NO. _____

TEST DATA - COMMENTS:

Checked By Bill at Pipestone.HARDNESS OF Teeth (cut off) Rotors (4 Pcs)
PN 368041) - RB-932) - RB-923) - RB-924) - RB-93HARDNESS OF splined shaft ADAPTER (GEAR) ON teeth.
RB 79-80Grain Structure of (cut) tooth off shaft adapterRB 80 Mat Not Gray Iron, Could be 1025-1030 SteelHARDNESS OF Intermediate Discs. MA 117501 RB-942 RB-96

TITLE ENERGIZING DISC BRAKE (11.00 x 8.00)

PL 36525

SHEET 1 OF 1 SHEETS

ITEM NO.	UNITS PER ASSY.	IDENTIFICATION NO.								DESCRIPTION
		1	2	3	4	5	6	7	8	
1		3	6	5	2	5				BRAKE-ENERGIZING DISC
2	1	AA	-	1	1	1	1	3		DISC ASSEMBLY-ACTUATING
3	4									SPRING-EXTENSION
4	2									STUD
5	2									NUT-JAM
6	1									BUSHING
7	4									BALL
8	2									DISC-ACTUATING
9	2									DISC CASTING-ACTUATING
10	2									LINK-PLAIN
11	8									INSERT
12	4									WASHER-LOCK
13	4									BOLT-HEX HD
14	2									DISC-INTERMEDIATE
15	1									BOOT
16	1									HOUSING
17										HOUSING, CASTING
18	1									HOUSING - COVER
19	1									HOUSING CASTING, COVER
20	1									ADAPTER - SPLINED
21	1									ADAPTER CASTING, SPLINED
22	4									DISC ASSEMBLY - MIDDLE
23	4									DISC-MIDDLE
24	4									DISC BLANK-MIDDLE (FINISHED)
25	8									LINING (AS 300K)
26	1									SEAL-OIL
27										
28										
29										
30										
31										
32										
33										
34										
35										
36										
37										
38										
39										
40										
41										
42										
43										

APR 16 1984

SYM	REVISIONS	DATE	ECO	SUPERSEDES	PROD. REL. #	T #
	PREPARED	12-6-83				
				CUSTOMER: EATON CORP		
				EQUIPMENT NAME & MODEL #:		
				PACKAGING:		P/N 2777

APPENDIX G

OPERATION AND MAINTENANCE OF THE
EATON TSO-11616
AUTOMATED MECHANICAL TRANSMISSION

OPERATION AND MAINTENANCE
of the
EATON TSO-11616 AUTOMATED MECHANICAL TRANSMISSION

Prepared Under:
Contract DAAE07-82-C-4121
For: U.S. Army-Tank Automotive Command
Research and Development Center
Warren, Michigan 48090

Prepared by:
Eaton Corporation
Engineering & Research Center
26201 Northwestern Highway
Southfield, Michigan 48037
Revised: March 1987

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Clutch Operation	3
Transfer Case Operation	4
Gear Ratios and Vehicle Speeds	5
Lubrication	6
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Exterior of Transmission	9
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INTRODUCTION

The Eaton TSO-11616 Automated Mechanical Transmission is a fully automatic transmission having 16-speeds forward and two speeds in reverse.

The transmission is connected to the engine by means of a typical truck two-plate clutch with ceramic lining material.

To operate the vehicle, the driver just starts the engine, selects the proper drive range for the road conditions, releases the brakes, depresses the throttle pedal and goes.

All of the shift decisions and synchronizing of the transmission are by the electronic controls, without any involvement being required by the driver.

SHIFT LEVER OPERATION

TRANSMISSION OPERATION

SELECT WHEN DRIVING ON

D OR R	PAVED OR GRAVEL ROADS
D3 OR D1	OFF-ROAD OR HILLY TRAILS
D1 OR R	SAND, MUD, OR STEEP HILLS

H - "HOLD" **TRANSMISSION WILL NOT SHIFT
WHEN "HOLD" IS SELECTED.**

Cab Instruction Label

The driver controlled shift lever is used to select the mode of operation of the transmission. The available operating modes are: REVERSE (R), NEUTRAL (N), DRIVE, DRIVE 3 (D3), DRIVE 1 (D1), AND HOLD (H).

Selection of the Drive mode (D) will result in 5th gear being selected as the starting gear. Upshifts and downshifts will be accomplished according to "on highway" shift profiles which favor fuel economy over peak performance. Downshifts below 5th gear are inhibited. This gear should be selected for driving on normal roads.

Selection of the Drive 3 mode (D3) will result in 3rd gear being selected as the starting gear. Upshifts and downshifts will be accomplished according to "off road" shift profiles which favor peak performance. Downshifts below 3rd gear are inhibited. This gear should be selected for driving off-road or on hilly trails.

Selection of the Drive 1 mode (D1) will result in 1st gear being selected as the starting gear. Upshifts and downshifts will be accomplished according to "off-road" shift profiles the same as in the Drive 1 mode. The Drive Low mode is intended to be used on very steep grades or in deep sand or mud where maximum pulling power is required.

Selection of Reverse mode will allow the vehicle to back up. Selection of Reverse (R) will provide a gear ratio compatible with the "on-highway" shift profiles. Selection of Reverse Low (RL) will provide a gear ratio compatible with the "off-road" shift profiles. The selection of either R or RL is done by the electronic control as a function of the last forward gear selected.

Selection of Neutral (N) will disengage the driveline from the engine. If the vehicle is stopped, the transmission will be placed in neutral. If the vehicle is moving the clutch will be disengaged, however, the transmission will remain in gear to facilitate re-engagement if a drive mode is selected or if the throttle is depressed. The engine can only be started if "N" is selected.

Selection of Hold (H) will prevent upshifts and downshifts. The Hold mode is intended to be used in situations where the operator does not want to allow the transmission to shift, such as slippery roads or low speed maneuvering.

If the vehicle comes to a stop with the lever in the "Hold" position, a starting gear will be selected, but the transmission will not upshift until a "Drive" range is selected.

ELECTRONIC CONTROLS

The electronic control system does not require any adjustment or maintenance.

Power for the electronics is provided by two lines each fused for 20 amps. The fuses are in line type. See vehicle wiring diagrams for location of fuses.

CLUTCH OPERATION

Clutch engagement is controlled by the throttle pedal. Inching of the vehicle can be achieved by very light throttle application.

Hill starting can be done by depressing the throttle pedal with the right foot while the left foot is on the brake pedal. As the driver feels torque in the driveline, the brake is released gradually and a smooth start will be achieved.

If the driver attempts to move the vehicle in a condition where there is not sufficient driveline torque, the clutch will engage after a delay causing the engine to stall or the wheels to spin out. This will alert the driver to use a lower gear or reduce the load on the vehicle.

The clutch assembly contains an automatic adjusting mechanism to adjust for clutch plate wear. The clutch therefore does not require any external or manual adjustments.

TRANSFER CASE OPERATION

A single speed transfer case is integral with the transmission. The transfer case contains a mechanical clutch which provides all wheel drive.

The control of the clutch remains with the driver under highway operating conditions when "D" is selected. The switch is on the dash panel.

When D1 or D3 is selected, the mechanical clutch is automatically engaged to provide the all wheel drive. If the automatic selection does not occur, the driver can override by using the switch on the dash panel.

GEAR RATIOS AND VEHICLE SPEED

<u>Gear</u>	<u>Ratio</u>	<u>MPH @ 2400 RPM</u>
1	11.12:1	3.8
2	9.28:1	4.5
3	7.76:1	5.4
4	6.42:1	6.5
5	5.36:1	8
6	4.47:1	9
7	3.74:1	11
8	3.09:1	13
9	2.61:1	16
10	2.18:1	19
11	1.82:1	23
12	1.51:1	28
13	1.26:1	33
14	1.05:1	40
15	.875:1	48
16	.724:1	57.6
R	10.23:1	4
R	7.31:1	6

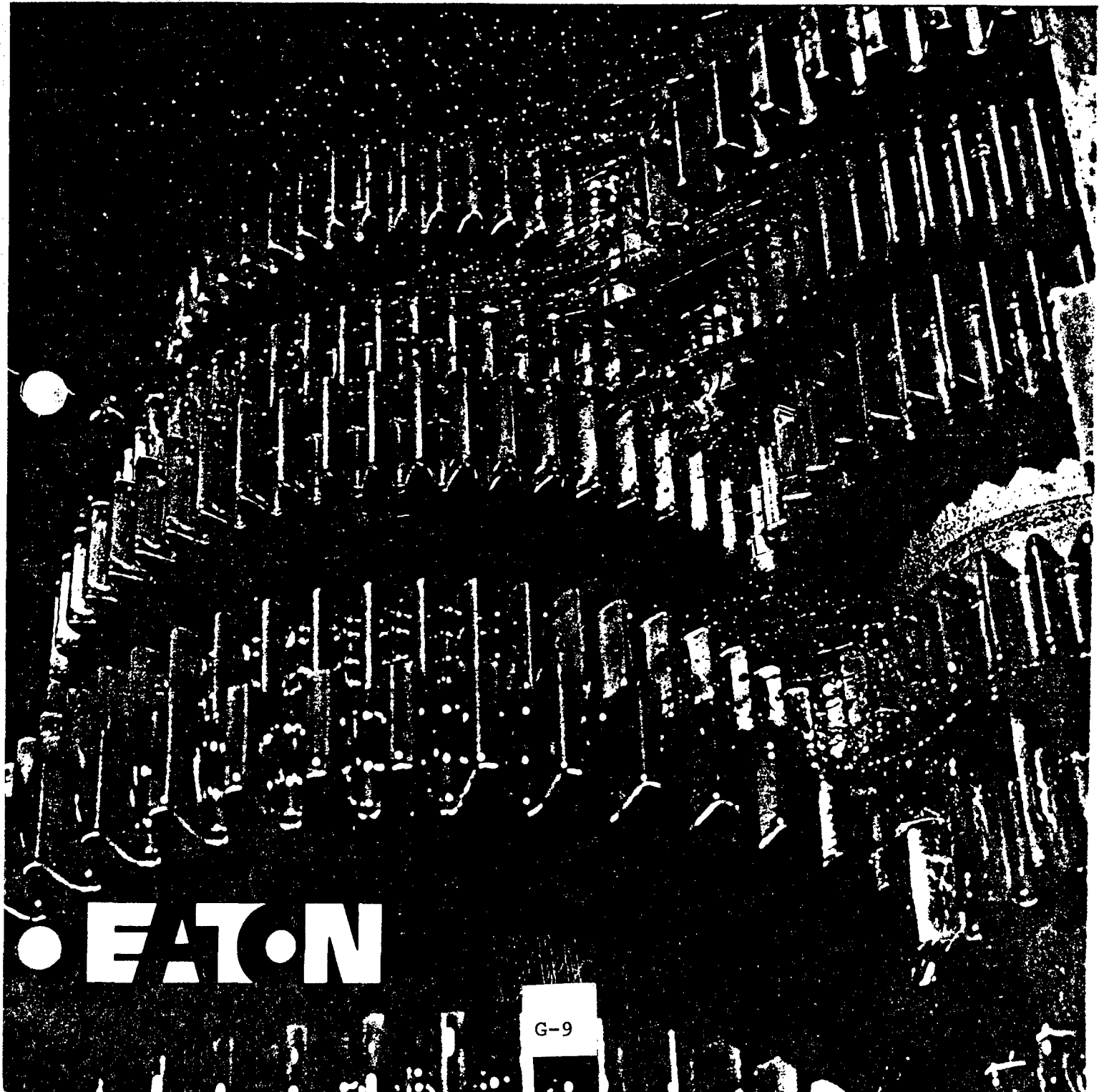
Assumptions:

Axle Ratio = 8.2:1

14R20 Tires = 421 Rev/Mile

Lubrication Recommendations

Fuller[®]
Transmissions



Proper Lubrication... the Key to long transmission life

Proper lubrication procedures are the key to a good all-around maintenance program. If the oil is not doing its job, or if the oil level is ignored, all the maintenance procedures in the world are not going to keep the transmission running or assure long transmission life.

Fuller® Transmissions are designed so that the internal parts operate in a bath of oil circulated by the motion of gears and shafts.

Thus, all parts will be amply lubricated if these procedures are closely followed:

1. Maintain oil level. Inspect regularly.
2. Change oil regularly.
3. Use the correct grade and type of oil.
4. Buy from a reputable dealer.

Lubrication Change and Inspection	
HIGHWAY USE	
First 3,000 to 5,000 miles (4827 to 8045 Km)	Change transmission oil on new units
Every 10,000 miles (16090 Km)	Inspect oil level. Check for leaks.
Every 50,000 miles (80,450 Km)	Change transmission oil.
OFF-HIGHWAY USE	
First 30 hours	Change transmission oil on new units.
Every 40 hours	Inspect oil level. Check for leaks.
Every 500 hours	Change transmission oil where severe dirt conditions exist.
Every 1,000 hours	Change transmission oil (Normal off-highway use).

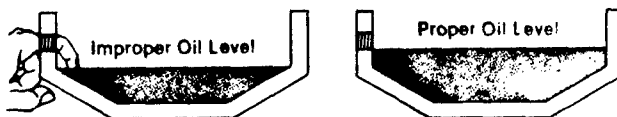
Oil filter should be changed at each oil change on units equipped with optional external oil filter, P/N 17237.

Recommended Lubricants		
Type	Grade (SAE)	Fahrenheit (Celsius) Ambient Temperature
Heavy Duty Engine Oil MIL-L-2104B, C or D or API-SF or API-CD (Previous API designations acceptable)	50	Above 10°F (-12°C.)
	40	Above 10°F (-12°C.)
	30	Below 10°F (-12°C.)
	15W-40	
Mineral Gear Oil with rust and oxidation inhibitor API-GL-1	90	Above 10°F (-12°C.)
	80W	Below 10°F (-12°C.)

The use of mild EP gear oil or multi-purpose gear oil is not recommended, but if these gear oils are used, be sure to adhere to the following limitations:

Do not use mild EP gear oil or multi-purpose gear oil when operating temperatures are above 230°F (110°C). Many of these gear oils, particularly 85W/140, break down above 230°F and coat seals, bearings and gears with deposits that may cause premature failures. If these deposits are observed (especially a coating on seal areas causing oil leakage), change to heavy duty engine oil or mineral gear oil to assure maximum component life and to maintain your warranty with Eaton. (Also see "Operating Temperatures".)

Additives and friction modifiers are not recommended for use in Fuller transmissions.



Proper Oil Level

Make sure oil is level with filler opening. Because you can reach oil with your finger does not mean oil is at proper level. **One inch of oil level is about one gallon of oil.**

Draining Oil

Drain transmission while oil is warm. To drain oil remove the drain plug at bottom of case. Clean the drain plug before re-installing.

Refilling

Clean case around filler plug and remove plug from side of case. Fill transmission to the level of the filler opening. If transmission has two filler openings, fill to level of both openings.

The exact amount of oil will depend on the transmission inclination and model. Do not over fill—this will cause oil to be forced out of the case through front bearing cover.

When adding oil, types and brands of oil should not be intermixed because of possible incompatibility.

Operating Temperatures

—With Heavy Duty Engine Oil and Mineral Oil

The transmission should not be operated consistently at temperatures above 250°F (120°C). However, intermittent operating temperatures to 300°F (149°C) will not harm the transmission. Operating temperatures above 250°F increase the lubricant's rate of oxidation and shorten its effective life. When the average operating temperature is above 250°F, the transmission may require more frequent oil changes or external cooling.

The following conditions in any combination can cause operating temperatures of over 250°F: (1) operating consistently at slow speeds, (2) high ambient temperatures, (3) restricted air flow around transmission, (4) exhaust system too close to transmission, (5) high horsepower, overdrive operation.

External oil coolers are available to reduce operating temperatures when the above conditions are encountered.

Transmission Oil Coolers are:

Recommended

- With engines of 350 H.P. and above with overdrive transmissions

Required

- With engines 399 H.P. and above with overdrive transmissions and GCW's over 90,000 lbs.
- With engines 399 H.P. and above and 1400 Lbs.-Ft. or greater torque
- With engines 450 H.P. and above

— With EP or Multipurpose Gear Oil

Mild EP gear oil and multipurpose gear oil are not recommended when lubricant operating temperatures are above 230°F (110°). In addition, transmission oil coolers are not recommended with these gear oils since the oil cooler materials may be attacked by these gear oils. The lower temperature limit and oil cooler restriction with these gear oils generally limit their success to milder applications.

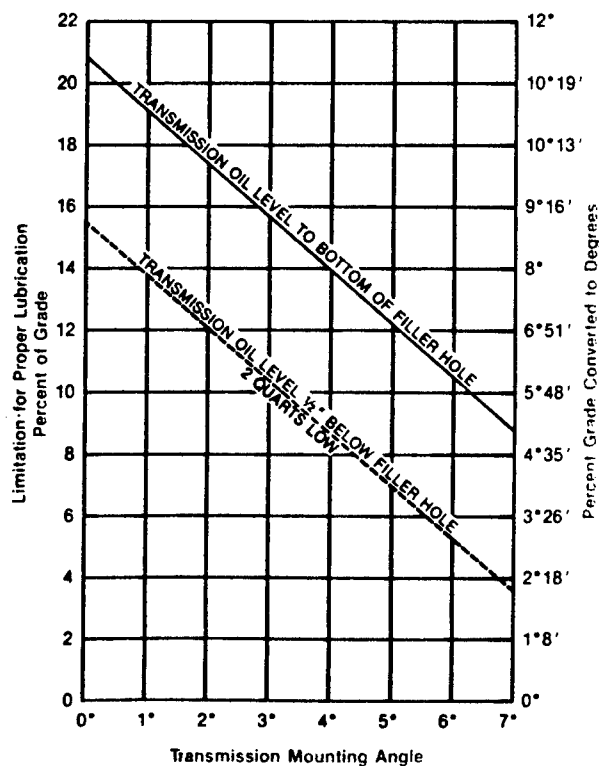
If the transmission operating angle is more than 12 degrees, improper lubrication can occur. The operating angle is the transmission mounting angle in the chassis plus the percent of upgrade (expressed in degrees).

The chart below illustrates the safe percent of upgrade on which the transmission can be used with various chassis mounting angles. For example: if you have a 4 degree transmission mounting angle, then 8 degrees (or 14 percent of grade) is equal to the limit of 12 degrees. If you have a 0 degree mounting angle, the transmission can be operated on a 12 degree (21 percent) grade.

Anytime the transmission operating angle of 12 degrees is exceeded for an extended period of time the transmission should be equipped with an oil pump or cooler kit to insure proper lubrication.

Note on the chart the effect low oil levels can have on safe operating angles. Allowing the oil level to fall ½" below the filler plug hole reduces the degree of grade by approximately 3 degrees (5.5 percent).

Proper Lubrication Levels are Essential!



Dotted line showing "2 Quarts Low" is for reference only. Not recommended.

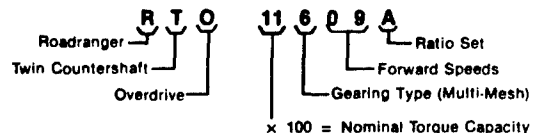
Transmission Oil Capacities

Previous Models			New Generation		
Twin Countershaft Models		Pints Liters			Pints Liters
T-905 Series		22 10	T-11605 Series		22 10
T-955AL Series		25 12	T-11606		26 12
T-955ALL Series		28 13	T-8607 Series		36 17
T-1056AA		29 14	T-11607 Series		36 17
TA-4510		25 12	T-14607 Series		37 17
Roadranger* Twin Countershaft Models					
RT-906		26 12	RTO-11607L		28 13
RTO-1157DL		27 13	RTO-11607LL		31 15
RTO-1157DLL		29 14	RT-8608L		27 13
RT-9508		25 12	RT-11608		26 12
RTO-958LL		28 13	RT-14608		28 13
RTO-1258LL		28 13	RTO-11608LL		29 14
RT-9509 Series		25 12	RTO-14608LL		29 14
RT-11509 Series		25 12	RT-8609		15 7
RT-12509 Series		25 12	RT-11609 Series		27 13
RT-610 Series		12 6	RT-12609 Series		27 13
RT-910 Series		25 12	RT-14609 Series		27 13
RT-1110 Series		25 12	RT-6610 Series		12 6
RT-12510 Series		25 12	RT-11610 Series		26 12
RT-613 Series		16 8	RT-12610 Series		26 12
RT-9513 Series		27 13	RT-14610 Series		26 12
RT-12513		27 13	RT-6613 Series		16 8
RT-915 Series		28 13	RT-11613 Series		28 13
RT-12515 Series		28 13	RT-14613 Series		29 14
			RT-15613 Series		29 14
			RT-11615 Series		28 13
			RT-14615 Series		30 14
			RT-15615 Series		30 14
Auxiliary Transmissions			Synchronized Transmissions		
AT-1202		11 5	FS-5106		18 9
2-A-92		12 6	FS-6106		19 9

Capacity figures listed are based on a 0° installation. Figures are approximate, as exact amount depends upon the degree of inclination of engine and transmission.

Capacity of transmissions equipped with PTO's or oil coolers would be greater than capacities listed.

Nomenclature:



EAT•N

Form No. 121-R4

9/86 - 20M - S.P.C.
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Eaton Corporation
Transmission Division
P.O. Box 4013
Kalamazoo, Michigan 49003
(616) 342-3344

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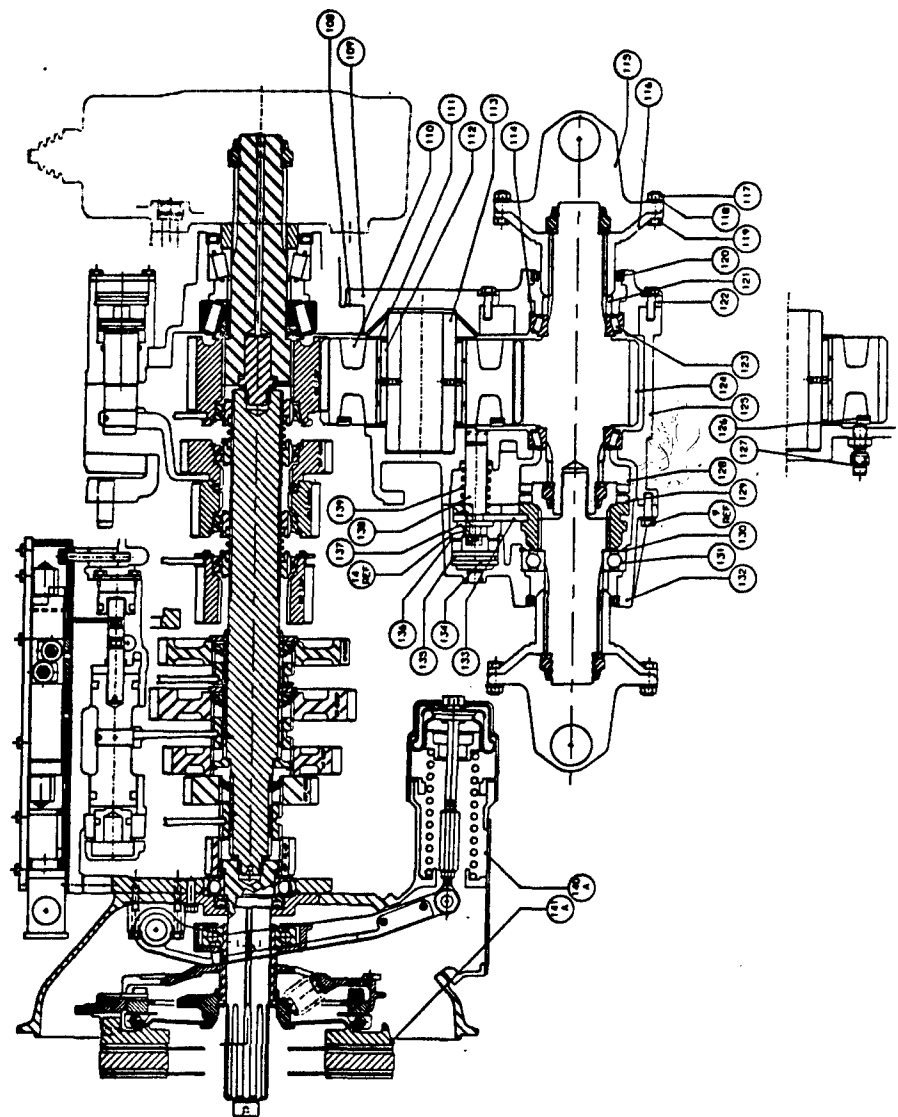
**EATON TSO-11616 AUTOMATED TRANSMISSION
WITH INTEGRAL TRANSFER CASE**

SPECIFICATIONS AND DATA

Rating	Input Torque	
	Transmission with T-Case	650 lb-ft
	Transmission w/o T-Case	1150 lb-ft
Mounting	Engine	SAE No. 1 or No. 2 clutch housing 3-bolt vertical mounting pad each side
	Vehicle	
Controls	Type	Electronic logic with pneumatic valves for complete automation of clutch and transmission
Clutch	Type	14 in. diameter, 2-plate, pull-type Ceramic
	Lining	
Gearing	Type	Constant mesh, spur gears
	Overall Ratio	15.34:1 with 16 speeds and 20% steps
	Transfer Case Ratio	0.875:1
	Gear Ratios with T-Case	
	First	11.12:1
	Second	9.28:1
	Third	7.76:1
	Fourth	6.42:1
	Fifth	5.36:1
	Sixth	4.47:1
	Seventh	3.74:1
	Eighth	3.09:1
	Ninth	2.61:1
	Tenth	2.18:1
	Eleventh	1.82
	Twelfth	1.51
	Thirteenth	1.26:1
	Fourteenth	1.05:1
	Fifteenth	0.875:1
	Sixteenth	0.724:1
	Low Reverse	10.23:1
	High Reverse	7.13:1
	Reverse Overall Ratio	14.13:1

SPECIFICATIONS AND DATA - continued

Oil System	Oil Type	SAE 30 Engine Oil
		MIL-L-2104D or MIL-L-46152
	Oil Cooler	Optional
	Capacity with T-Case	23 Quarts
	Capacity w/o T-Case	15 Quarts
Dimensions (with T-Case)	Length (w/o Parking Brake)	39.08 inches
	Width	26.90 inches
	Height	26.12 inches
	Weight (dry)	1290 lbs.
Dimensions (without T-Case)	Length (w/o Parking Brake)	42.20 inches
	Width	21.10 inches
	Height	22.63 inches
	Weight (dry)	956.5 lbs.



1. TITLE 2. DATE 3. DRAWN BY 4. CHECKED BY 5. APPROVED BY 6. PART NO. 7. QUANTITY 8. MATERIAL 9. FINISH 10. TOLERANCES 11. DIMENSIONS 12. WEIGHT 13. VOLUME 14. SURFACE AREA 15. CENTER OF GRAVITY 16. MOMENT OF INERTIA 17. STRESS 18. STRAIN 19. ELONGATION 20. REDUCTION OF AREA 21. TENSILE STRENGTH 22. YIELD STRENGTH 23. COMPRESSIVE STRENGTH 24. SHEAR STRENGTH 25. TORSION STRENGTH		26. PART NO. 27. QUANTITY 28. MATERIAL 29. FINISH 30. TOLERANCES 31. DIMENSIONS 32. WEIGHT 33. VOLUME 34. SURFACE AREA 35. CENTER OF GRAVITY 36. MOMENT OF INERTIA 37. STRESS 38. STRAIN 39. ELONGATION 40. REDUCTION OF AREA 41. TENSILE STRENGTH 42. YIELD STRENGTH 43. COMPRESSIVE STRENGTH 44. SHEAR STRENGTH 45. TORSION STRENGTH
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